N73-30219
CR-134006

REPORT FOR NASA-JSC CONTRACT

NAS9-7644

EXTRAVEHICULAR MOBILITY UNIT THERMAL SIMULATOR FOR "J" MISSION

REPORT NO. T155-04

31 July 1973

SUBMITTED BY

VOUGHT SYSTEMS DIVISION
LTV AEROSPACE CORPORATION
P. O. BOX 5907 - DALLAS, TEXAS - 75222

TO

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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1.0 SUMMARY

This report presents the analytical methods, thermal model, and user's instructions for the SIM bay Extravehicular Mobility Unit (EMU) routine. This digital computer program was developed for detailed thermal performance predictions of the crewman performing a Command Module extravehicular activity during transearth coast. It accounts for conductive, convective, and radiative heat transfer as well as fluid flow and associated flow control components.

The program is a derivative of the Apollo lunar surface EMU digital simulator (Reference 1). It has the operational flexibility to accept card or magnetic tape for both the input data and program logic. Output can be tabular and/or plotted and the mission simulation can be stopped and restarted at the discretion of the user. The program was developed for the NASA-JSC Univac 1108 computer system and several of the above capabilities represent utilization of unique features of that system. Analytical methods used in the computer routine are based on finite difference approximations to differential heat and mass balance equations which account for temperature or time dependent thermo-physical properties.

The user's manual and supporting appendices provide complete routine instructions for problem submission in compliance with current NASA-JSC Computation and Analysis Division procedures.

2.0 INTRODUCTION

This report describes the SIM bay EMU digital simulator (routine) and the Baseline Thermal Model developed by the LTV Aerospace Corporation. The EMU thermal model is the same as the Apollo Lunar Surface EMU thermal model (Reference 1) with the portable life support system (PLSS) and the remote control unit deleted and the Command Module ventilation gas loop added. The Lunar Roving Vehicle thermal model was replaced by a model of the SIM bay. More detailed information on the thermal model is presented in Section 4.0. The routine simulates the crewman in the suited, partially suited and shirtsleeve modes.

The routine and thermal model have been correlated to only a limited extent because adequate comparison data was unavailable. Since the Apollo suit was used for lunar surface and in flight EVA's, suit multilayer insulation conductances are correlated from the lunar surface EVA model. The ventilation gas loop simulation was verified against component specification data.

3.0 ANALYTICAL METHODS

Sections 3.1 through 3.4 describe generalized heat balance and flow system calculation methods used in this computer routine which may be applied to other thermal simulation models. Sections 3.5 through 3.8 describe specialized analytical characterizations which have been created for the SIM bay Extravehicular Mobility Unit (EMU) program formulation.

Differential equations which describe conductive, convective, and radiative heat transfer, and internally generated heat as well, are solved by the familiar explicit finite difference approximation technique (Reference 2). In this technique the subject of the analysis is divided into lumps which are considered to be isothermal for evaluation of thermal properties and heat capacitance effects, and which are considered to have temperatures located at their geometric centers (nodes or lumps) for conduction effects.

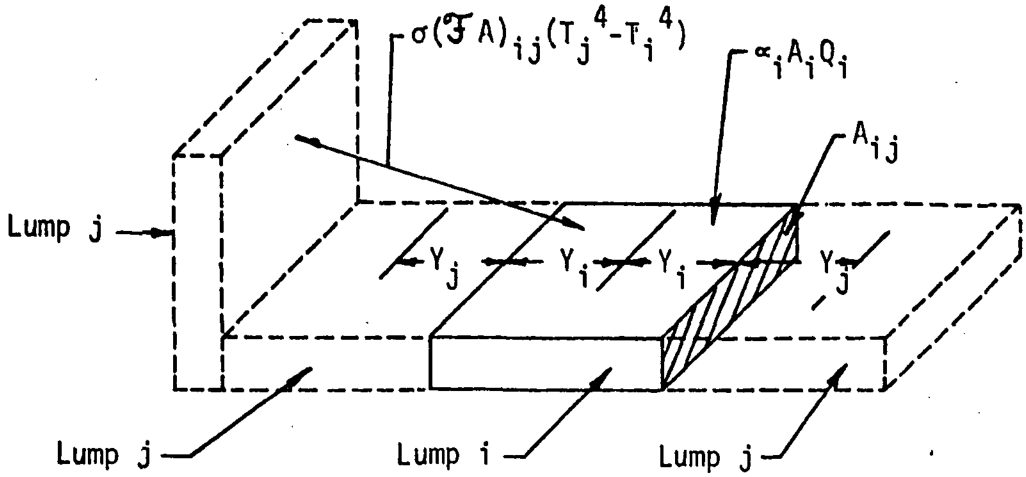
3.1 Thermal Analysis

In the computer routine, lumps are classified as: (1) structure lumps; (2) tube lumps; and (3) fluid lumps. In general, structure lumps are lumps which are not in contact with any flowing fluid. Tube lumps are lumps which are in contact with a flowing fluid, as well as structure lumps and other tube lumps. Fluid lumps are flowing or stagnant liquid or gas lumps which experience convective heat transfer interchange with tube lumps. These three classifications, which are discussed below, govern much of the computer routine input data format discussed in Section 5.7. Each lump must be numbered, and the lump numbers in each classification start at 1 and go consecutively through the maximum number for that classification.

As will be seen later, nodes requiring special analysis do not necessarily follow the classifications described above. In most instances where the classifications break down, the node is made a structure node which requires less interrelated input data.

The finite-difference equations used for each lump classification are described below.

3.1.1 Structure Lumps (illustrated by the sketch below)



$$w_i c_i \frac{T_i' - T_i}{\Delta\tau} = \sum_j U_{ij}(T_j - T_i) + \alpha_i A_i Q_i + \sum_j \sigma \mathcal{F}_{i-j} A_i (T_j^4 - T_i^4) \quad (1)$$

Heat Stored — Net Heat Flux

Equation (1) may be rewritten in the form:

$$T_i' = T_i + \frac{\Delta\tau}{w_i c_i} \left[\sum_j U_{ij}(T_j - T_i) + (\alpha A)_i Q_i + \sum_j \sigma(\mathcal{F}A)_{ij}(T_j^4 - T_i^4) \right] \quad (2)$$

Equation (2) is the basic form of the structure lump heat balance equation.

where:

i = lump number (data input)

T_i = temperature of lump i at time τ, °R (Routine input and output are in °F)

T_i' = temperature of lump i at time $\tau + \Delta\tau$, °R

$\Delta\tau$ = time increment of next step in calculation as determined by convergence criteria within the routine (see Section 3.2.1) hrs

w_i = weight of lump i, (input data - lbs)

c_i = specific heat of lump i. This quantity is entered as a table of specific heat (BTU/lb-°F) versus temperature in °F.

U_{ij} = the conductance between structure lump i and adjacent structure lumps, j, BTU/hr-°F

$$U_{ij} = \frac{1}{\frac{R_i}{k_i} + \frac{R_j}{k_j}}$$ This form of U_{ij} permits an accounting of temperature dependent dissimilar materials in adjacent nodes. (3)

R_i = that portion of the conduction resistance from lump i to j which is attributed to i, $\frac{Y_i}{K_i A_{ij}}$ (input as R_1,hr-°F/BTU)

R_j = that portion of the resistance from lump i to j which is attributed to j, = $\frac{Y_j}{K_j A_{ij}}$ (input as R_2,hr-°F/BTU)

where: Y_i = is that portion of the conduction path length between node i and j which lies in lump i

Y_j = is that portion of the conduction path length between node i and j which lies in lump j

A_{ij} = is the effective conduction area between lumps i and j

K_i = is the thermal conductivity of lump i

K_j = is the thermal conductivity of lump j

k_i = thermal conductivity of lump i at the present temperature (time τ) normalized by the thermal conductivity at which R_i was evaluated, i.e., K_i/K_{R_i}. This quantity is entered as a table of normalized conductivity versus temperature in °F for each lump, dimensionless

k_j = thermal conductivity of lump j at the present temperature (time τ) normalized by the thermal conductivity at which R_j was evaluated, i.e., K_j/K_{R_j}, dimensionless

In the case of constant thermal conductivity, the entire resistance may be calcuated as R_i, and R_j is entered as 0.0. This is desirable since

it saves data space in the computer core.

T_j = temperature of adjacent lumps at time τ (lump numbers, j, which are connected to lump i are data input), °R

$(\alpha A)_i$ = incident heat application area for lump i, (data input sq. in.). This quantity can be entered as absorptance (α_i) times area (A_i) or as area alone depending on how Q_i is entered. BTU/hr

Q_i = incident heat on lump i, BTU/ft^2-hr. This quantity is entered as a table versus time in hours. Obviously absorbed heat (α Q) could be entered here in which case α A would be entered as area only.

σ = Stefan-Boltzmann constant, 0.173 x 10^{-8} BTU/hr-ft^2(°R)^4

$(\mathcal{F}A)_{ij}$ = Gray-body configuration factor (a function of surface emittances, areas, and geometry) from lump i to lump j, sq. ft. (data input - sq. in.)

The routine calculates the energy entering a structure lump for each connection to that lump prescribed in the data. The calculated energy is summed algebratically and stored in the TSQRAT array until the structure temperatures are updated.

3.1.2 Tube Lumps

The development of the equations for tube lumps departs in subtle but significant ways from the explicit finite difference method of the structure equations. Tube lump temperatures are calculated using a hybrid implicit-explicit numerical differencing technique (Reference 3). The advantage of the hybrid finite difference equations is that they are numerically stable for relatively large time increments. The hybrid form of the tube temperature equation is written as follows:

$$\dot{Q}_{STORED} = \dot{Q}_{CONV} + \dot{Q}_{COND} + \dot{Q}_{RAD} + \dot{Q}_{ABSORBED}$$

$$\frac{wc_i}{\Delta\tau}(T_i' - T_i) = h_f A_f (T_f' - T_i') + \sum_j (UA)_{ij}(T_j - T_i) + \sum_j \sigma(\mathcal{F}A)_{ij}(T_j^4 - T_i^4) + \dot{Q} \qquad (4)$$

where: h_f = convective heat transfer coefficient, BTU/(hr-ft^2-°F)

A_f = area for convective heat transfer, ft^2 (data input - in^2)

T_f = updated temperature of fluid lump associated with tube lump i, °R

T_j = tube or structure lump j to which tube lump i is connected

The input data for tube lumps includes all of the data input required for structure lumps plus the lump number of the enclosed fluid lump and the convective heat transfer area, A_f. Data required for computing the heat transfer coefficient is given with the enclosed fluid lump input data. Heat transfer coefficient computation is discussed in Section 3.3.

To solve for T_i' explicitly, it is necessary to have the updated fluid temperature, T_f'.

$$T_i' = \frac{\frac{(wc)_i}{\Delta\tau} T_i + h_f A_f' + \sum_j (UA)_{ij}(T_j - T_i) + \sum_j \sigma(\mathcal{F}A)_{ij}(T_j^4 - T_i^4) + (\alpha A)_i Q_i}{\frac{(wc)_i}{\Delta\tau} + h_f A_f} \qquad (5)$$

Therefore, the fluid temperatures must be known or calculated at each time increment ($\Delta\tau$) prior to the tube lump calculation.

3.1.3 Fluid Lumps

Fluid lump temperatures are calculated using the hybrid finite difference based on the following energy balance.

$$\dot{Q}_{STORED} = \dot{Q}_{\substack{MASS\\FLUX}} + \dot{Q}_{CONV}$$

$$\frac{(wc)_f}{\Delta\tau}(T_f' - T_f) = \dot{w}c_p(T_{fu}' - T_f') + \sum_t (hA)_t (T_t' - T_f') \qquad (6)$$

Solving for T_f' and substituting equation (5) for T_t' :

$$T_f' = \frac{\frac{(wc)_f}{\Delta\tau} T_f + \dot{W}C_p T_{fu}' + \sum_t (hA)_t \left(\frac{\frac{(wc)}{\Delta\tau}_t T_t + \sum_j (UA)_j (T_j - T_t)}{\frac{wc}{\Delta\tau}_t + (hA)_t} \right)}{\frac{(wc)_f}{\Delta\tau} + \dot{W}C_p + \sum_t \frac{(hA)_t \frac{(wc)_t}{\Delta\tau}}{\frac{(wc)}{\Delta\tau}_t + (hA)_t}} \tag{7}$$

Inspection of equation (7) reveals the requirement for the updated upstream fluid temperature, T_{fu}' , while the other temperatures are known from the previous time increment. Each separate system has a system starting point from which the temperature calculations proceed in the direction of the flow each iteration. Therefore T_{fu}' is established initially at the system starting point in a closed loop system and then calculated on subsequent iterations. In an open system the T_{fu}' must be known as a function of time at the origination of flow.

3.2 Convergence and Accuracy Criteria

The heat transfer equations used in the computer routine described herein are based on explicit and implicit-explicit hybrid methods of finite difference solution. With the first method, the future temperature of any structure lump is evaluated from the present temperature of surrounding lumps and the thermal environment. The validity of this type of solution depends on satisfying criteria for stability, oscillation, and truncation error minimization. The hybrid method was employed to remove the heat transfer coefficient from the stability criteria for the tube lump analysis.

3.2.1 Stability

The term stability usually refers to errors in equation solution that progressively increase or accumulate as the calculations proceed. Clark (Reference 4) concludes that any explicit forward difference equation will yield stable results for the future temperatures of any lump if the coefficients of the present lump temperature are at least zero or have the same sign as the other coefficients of known temperatures. This stability criterion defines the size of the time step to be used with the basic equations. The

equations used in the computer routine are rearranged below to show the development of the stability requirement for structure lumps. It should be noted that failure to meet this stability criteria means only that the solution may be unstable and not that it is. For structure lumps, Equation (2) may be written as:

$$T_i' = \frac{\Delta\tau}{w_i c_i}\left[\sum_j U_{ij}T_j + (\alpha A)_i Q_i + \sum_j \sigma(\mathcal{F}A)_{ij}(T_i^2+T_j^2)(T_i+T_j)T_j\right]$$

$$+ T_i\left[1 - \frac{\Delta\tau}{w_i c_i}\left(\sum_j U_{ij} + \sum_j \sigma(\mathcal{F}A)_{ij}(T_i^2+T_j^2)(T_i+T_j)\right)\right] \qquad (8)$$

According to Reference (5) the linearized radiation can cause oscillations when the radiative coupling is dominant and suggests replacing

$$\sum \sigma(\mathcal{F}A)_{ij}(T_i^2+T_j^2)(T_i+T_j) \quad \text{with} \quad 4\sigma \sum (\mathcal{F}A)_{ij}T_i^3$$

in the stability criterion equation. For the coefficient of T_i to be positive,

$$\Delta\tau \le \frac{w_i c_i}{\sum_j U_{ij} + 4\sigma T_i^3 \sum (\mathcal{F}A)_{ij}} \qquad (9)$$

An identical stability equation exists for the tube lump Equation (5). The hybrid technique as written for the fluid lump temperature (Equation 7) is inherently stable according to Clark's criterion.

3.2.2 Oscillation

Even though a solution is stable, it may oscillate around a correct mean value. An oscillatory condition is dependent on the problem boundary conditions and the node spacing. In cases where oscillation occurs, this undesirable condition may be damped or eliminated by use of a $\Delta\tau$ smaller than the limiting value specified by equation (13). This is accommodated by the input of TINCMN described in Section 3.2.4.

3.2.3 Truncation Error

The truncation error in the routine solution results from replacing derivatives with finite differences. In order to provide a measure of the accumulated truncation error, results for smaller time and space increments (subject to stability and oscillation criteria) should be compared. Chu (Reference 6) recommends halving the space increment and quartering the time increment to obtain an estimate of the error in a numerical result. In general, an investigation of truncation error must be made by changing lump sizes for each type of problem to determine the maximum size of isothermal lumps that can be used for a valid solution.

The truncation error has been shown to be of the form A + B (Ref. 4) where A is proportional to the time increment and B is proportional to the square of the lump linear dimension. LTV experience indicates that time truncation error (A) is relatively small (≈ 3 percent) if the time increment satisfies the stability criteria. The spatial truncation error (B) can be evaluated at steady state.

3.2.4 Steady State Nodes

In a large complex thermal model such as the one to which this routine is applied, it is generally desirable to decrease computation time by having the temperature calculations advance at a larger time increment, $\Delta\tau$, than the calculated maximum time increment, $\Delta\tau_{max}$ (equation 9), for some individual lumps. For this reason the routine was setup so that the computing interval, TINCMN, is supplied by the user on Parameter Card 2, Section 5.7.1. In order to prevent oscillation in those lumps having a $\Delta\tau_{max}$ less than TINCMN, the routine tests TINCMN against the $\Delta\tau_{max}$ for each lump, and in cases where $\Delta\tau_{max}$ is smaller, the heat balance equation is modified so that the individual values of $\Delta\tau_{max}$ are applied to compute T' for these particular lumps. This is illustrated below for a structure lump with no radiation or incident heat flux. The operation is commonly referred to as "overriding" these particular lumps.

$$T_i' = T_i + \frac{\Delta\tau}{w_i c_i} \sum U_{ij}(T_j - T_i) \tag{10}$$

$$\Delta\tau_{max} = \frac{w_i c_i}{\sum U_{ij}} \tag{11}$$

Substitute (11) into (10) and

$$T_i' = T_i + \frac{\sum U_{ij}(T_j - T_i)}{\sum U_{ij}} = T_i + \frac{\sum U_{ij}T_i}{\sum U_{ij}} - T_i$$

$$T_i' = \frac{\sum U_{ij}T_i}{\sum U_{ij}} \quad \text{or} \quad \sum U_{ij}(T_j - T_i') = 0 \tag{12}$$

Thus, T_i' is the temperature which would yield an equilibrium heat balance with lump i surrounding temperatures of T_j. While this feature allows greater run speed and prevents "overridden" lump oscillation, care should be exercised to prevent large errors which can result from "overriding" two adjacent lumps.

3.3 Fluid Heat Transfer Coefficient

Commonly used equations for determining both laminar and turbulent fluid heat transfer coefficients were programmed into the computer routine. An option was also included to permit the program user to input heat transfer coefficient as a function of flow rate in a table (Card 2, Fluid Data Cards). This option is useful for characterizing convective heat transfer in fluid system components when applicable performance data is available.

The use of theoretical solutions based on the assumption of constant fluid properties may introduce errors for fluids where viscosity is a strong function of temperature. The EMU uses two fluids; oxygen and water, the latter has a significant viscosity variation with temperature. This variation is accounted for through curve data input (Section 5.7.16).

3.3.1 Laminar Flow

Both the thermal entry length and the fully developed flow regimes must be considered to properly evaluate a laminar flow heat transfer coefficient. The thermal entry length region is usually considered to include those values of $(1/Re\ Pr)(L/D_h)$ below .050.

Results are shown in Figure 3-1 for theoretical local and mean Nusselt Numbers obtained by the Graetz solution for circular tubes with uniform surface temperature (Reference 7). The solutions exhibit an asymptotic approach to a

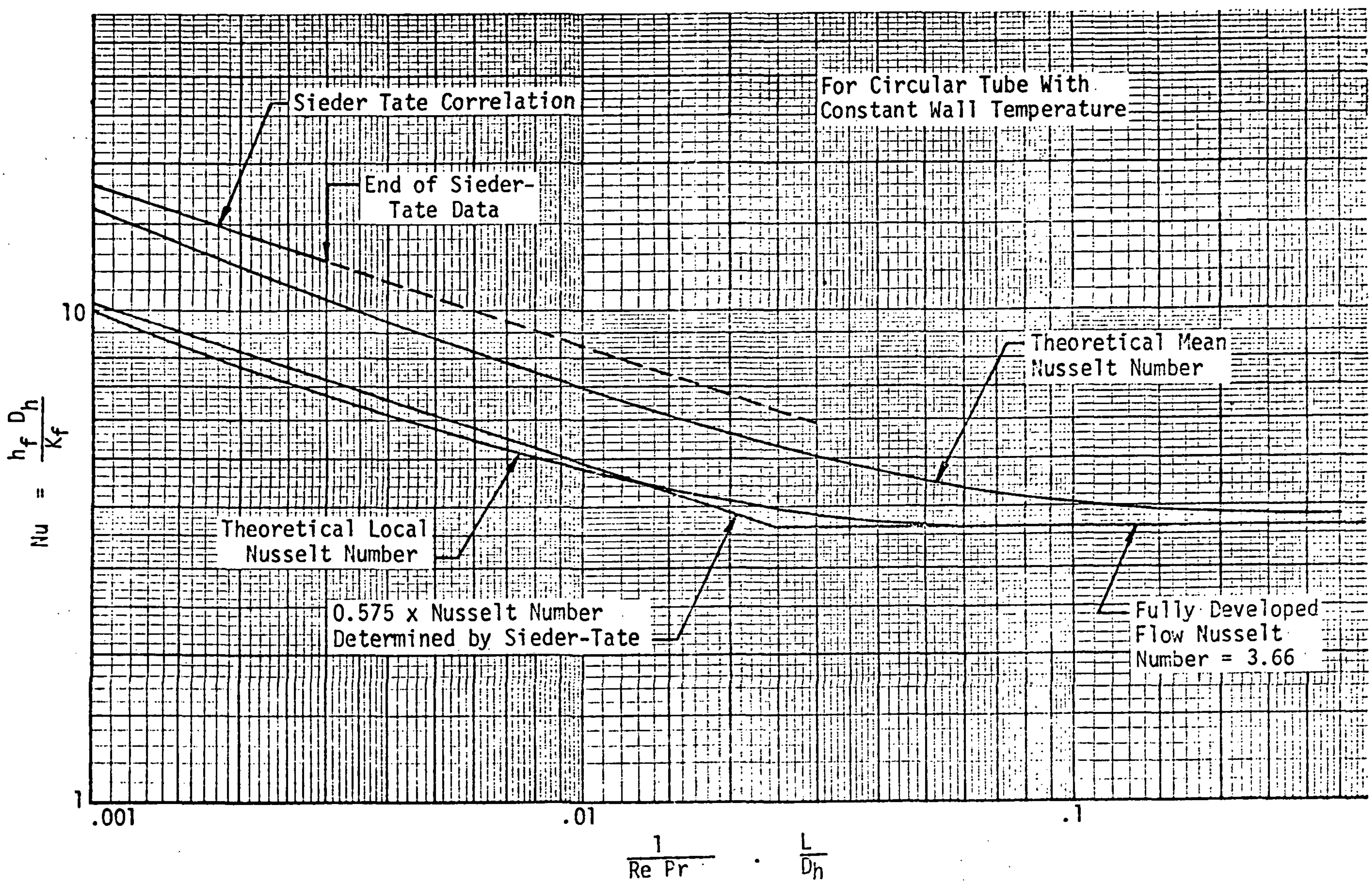


FIGURE 3-1 LAMINAR FLOW NUSSELT NUMBERS

fully developed flow Nusselt Number of 3.66. A plot of the Sieder-Tate equation (Reference 8) which represents an experimental correlation of test data for $(1/RePr)(L/D_h)$ of 0.003 and below is also shown in Figure 3-1. The entry length heat transfer coefficient equation programmed in the computer routine is the Sieder-Tate correlation modified by a factor of 0.575. This equation is shown to provide an adequate fit for the theoretical local heat transfer coefficients which are needed for the individual lumps in the computer routine.

$$h_f = (1.86)(.575)\, K_f/D_h \left[\frac{Re\ Pr}{L/D_h}\right]^{1/3} \qquad (13)$$

where:

h_f = convective heat transfer coefficient, BTU/hr-ft^2-°F
K_f = fluid thermal conductivity, BTU/hr-ft-°F
L = length from tube entrance, ft
D_h = tube hydraulic diameter = 4 CSA/WP, ft
CSA = cross sectional area of tube, ft^2 (data input - in^2)
WP = wetted perimeter of tube, ft (data input - in)
Re = Reynolds number, dimensionless
Pr = Prandtl number, dimensionless

The values calculated with Equation (13) are compared with the values calculated by the fully developed flow heat transfer equation:

$$h_f = 3.66\, K_f/D_h \qquad (14)$$

and the higher value is used in the heat balance equation.

In this routine it is also possible to have stagnant fluid in flow systems. When this occurs equation (14) is used to determine the heat transfer coefficient to the fluid.

3.3.2 Turbulent Flow

The correlation of equation (15), recommended in Reference 9, is used to determine heat transfer coefficients at Reynolds numbers greater than 2000.

$$h_f = .023\, \frac{K_f}{D_h}\, (Re)^{.8}\, (Pr)^{1/3} \qquad (15)$$

In turbulent flow the undeveloped region of heat transfer is short (≈ 4 diameters) such that for most cases it will constitute only a small portion of the total internal heat transfer region.

3.4 Fluid Pressure Loss

The flow system pressure loss is calculated by the Fanning equation with a dynamic head loss factor (K) added. The pressure loss for each fluid lump is calculated by:

$$\Delta P = 4\, f \frac{FLL}{D_h} \frac{\rho V^2}{2} + K \frac{\rho V^2}{2} = \frac{\dot{w}^2}{2\rho CSA^2} \left[\frac{f(WP)FLL}{CSA} + K \right] \quad (22)$$

where

f = friction factor 16/Re for Reynolds Numbers less than 2000 and is read from input data for Reynolds Numbers greater than 2000 (NFFC, Fluid Data Card 2). The laminar flow friction factor may also be multiplied by FRE, Fluid Data Card 2 to account for non-circular pipe flow.

FLL = fluid lump length (not necessarily equal to tube lump length)

K = number of fluid dynamic head losses

$\dot{w}$ = tube fluid flow rate, lb/hr

WP = wetted perimeter, ft (data input - in)

CSA = fluid cross section area, ft^2 (data input - in^2)

D_h = tube hydraulic diameter - 4 CSA/WP, ft

ρ = fluid density, lb/ft^3

v = fluid velocity, ft/hr

The fluid lump type cards provide for inputs of (K) which can be different for each fluid lump type. The term is used to account for pressure losses in tube entrance regions, bends, contractions, and expansions. Entrance pressure losses for varying duct geometries (Reference10) may also be specified by (K).

3.5 Flow System Characterization

There are three flow systems involved in the simulation of a crewman performing an in-flight Extravehicular Activity (EVA). These systems are the vehicle environmental control system (ECS) coolant loop, the ventilation oxygen loop and the oxygen purge system.

Only a short segment of the much larger ECS coolant loop is simulated. The ECS coolant loop is only important in the analyses to the extent that it interacts with the ventilation oxygen loop at the restrictors. Therefore the ECS coolant loop is characterized beginning upstream of the first restrictor and ending downstream of the third restrictor. Notice in Figure 3-2 that the coolant loop and ventilation oxygen loop are arranged for parallel flow through the restrictors. The coolant loop adds heat to the oxygen through the restrictors to assure that the oxygen leaves the restrictors in the gaseous phase.

As with the coolant loop, the complete ventilation oxygen loop is not characterized. The cryogenic oxygen tanks and the tubing connecting the tanks to the restrictors are omitted. Characterization of the ventilation oxygen loop begins at the inlet to the restrictors and includes the components at the EVA/IVA panel, EVA umbilical, suit control unit (SCU), suit, and pressure control valve (PCV). The condition (temperature and pressure) of the oxygen is specified in the input data for each restrictors inlet. Due to the manner in which the cryo tanks are manifolded, the inlet temperature and pressure of two of the restrictors should always be input as coming from a single tank. The restrictors are in parallel and the flowrate in each restrictor is iterated until the pressure drops are equal and the sum of the restrictor flows is equal to the total oxygen flow. Total oxygen flow is determined from calculations on the SCU fixed orifice.

The third flow system, the Oxygen Purge System (OPS) (Figure 3-3), is identical to the OPS used during lunar surface EVA. High pressure oxygen is regulated by the suit purge control valve which can be set for either a 4 or 8 pound per hour suit flow. The OPS backs up the ventilation oxygen system in case of flow stoppage or excessive carbon dioxide build-up in the suit.

3.6 Crewman Characterization

The simulator has incorporated the 41-node metabolic man simulation developed by the National Aeronautics and Space Administration (NASA) - Manned Spacecraft Center (MSC) (Reference 11). Program logic change was necessary to interface the 41-node man with the simulator but the basic relationships representing the thermal regulatory processes are unchanged. The principle area of significant change is at the man's skin/environment interface. Figure 3-4 describes the man's skin/environment as modeled in the simulator.

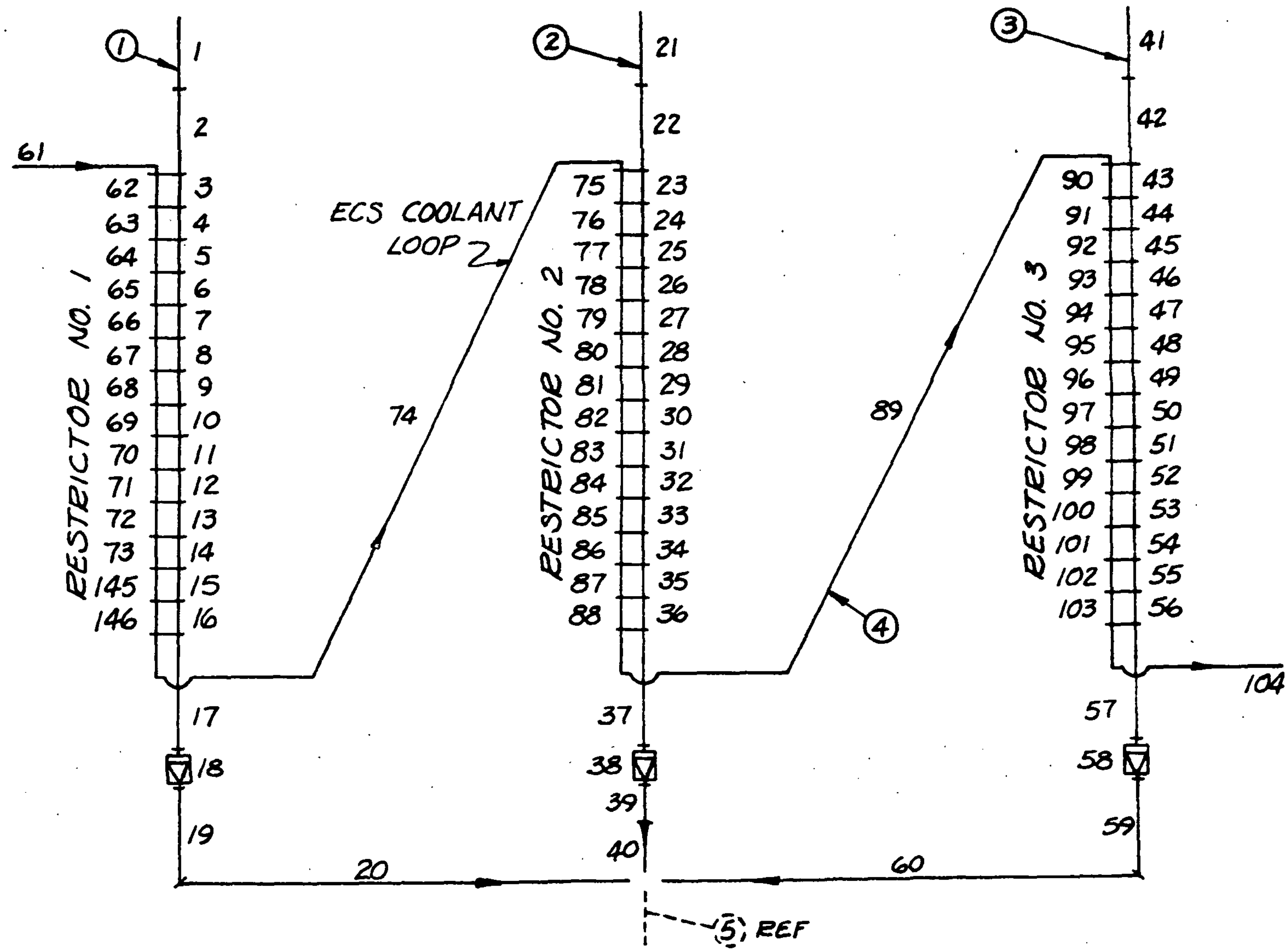


FIGURE 3-2 ECS COOLANT/VENTILATION OXYGEN SYSTEM SCHEMATIC

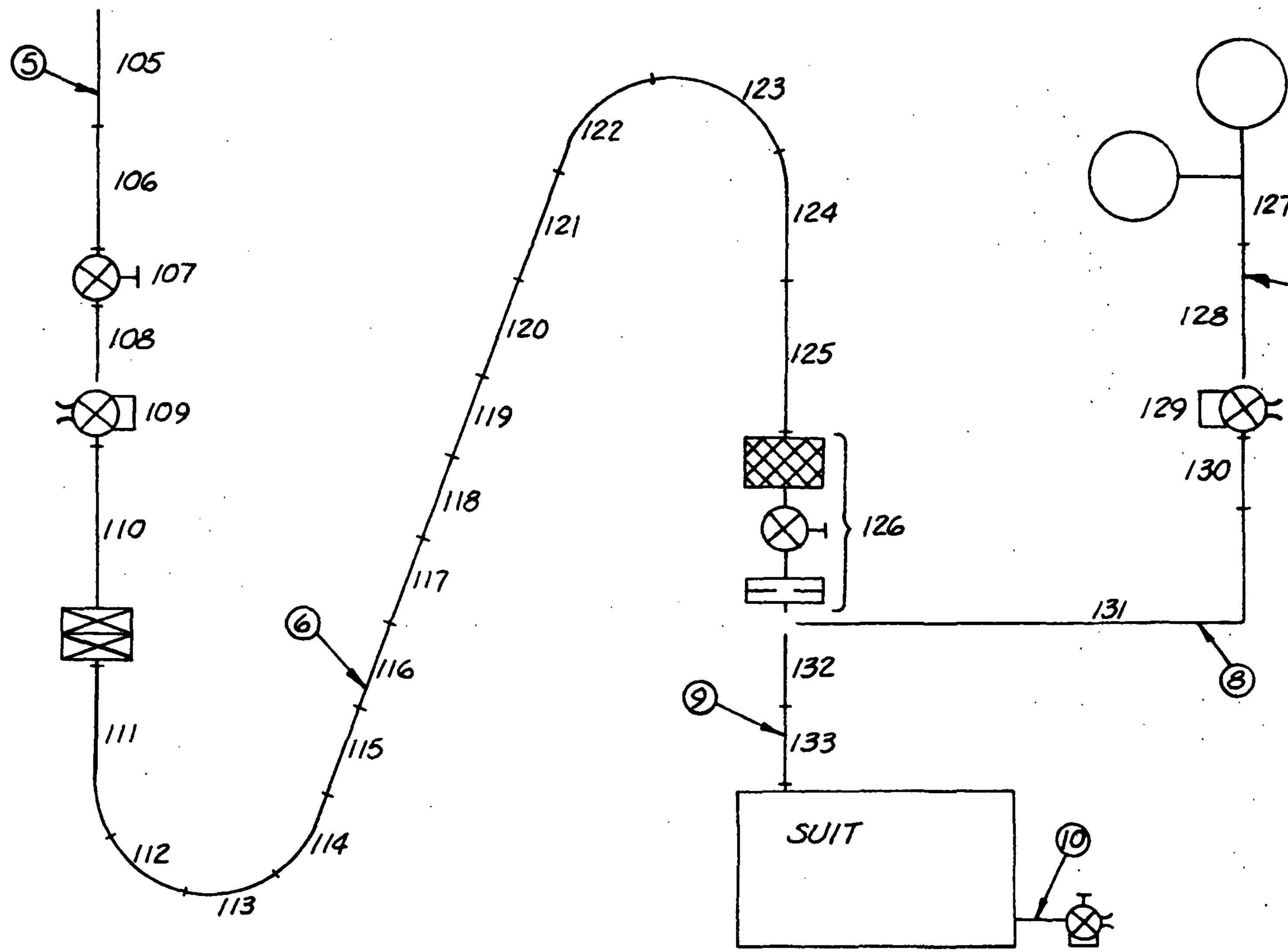


FIGURE 3-2 (CONT'D) ECS COOLANT/VENTILATION OXYGEN SYSTEM SCHEMATIC

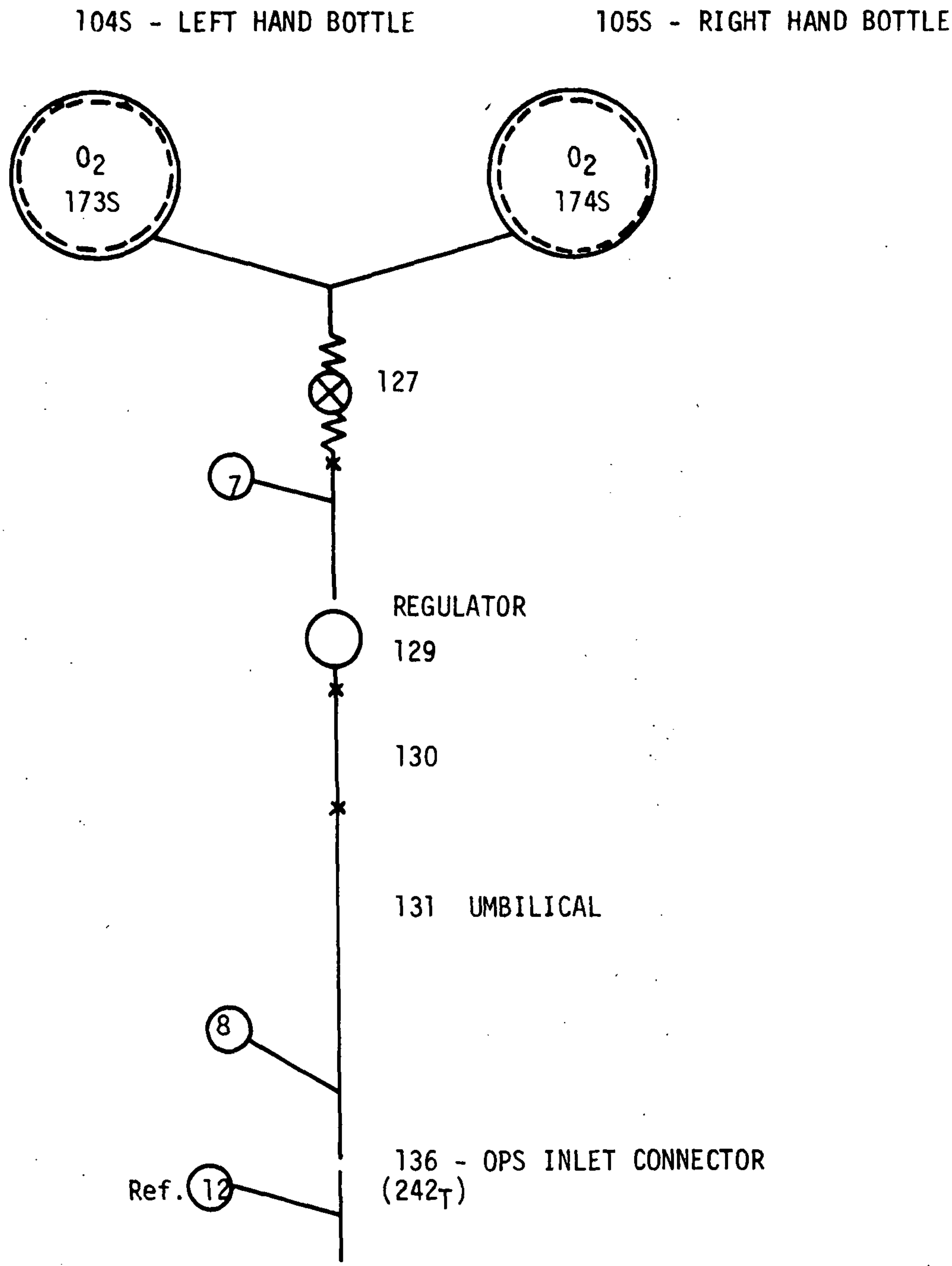


FIGURE 3-3 OXYGEN PURGE SYSTEM SCHEMATIC

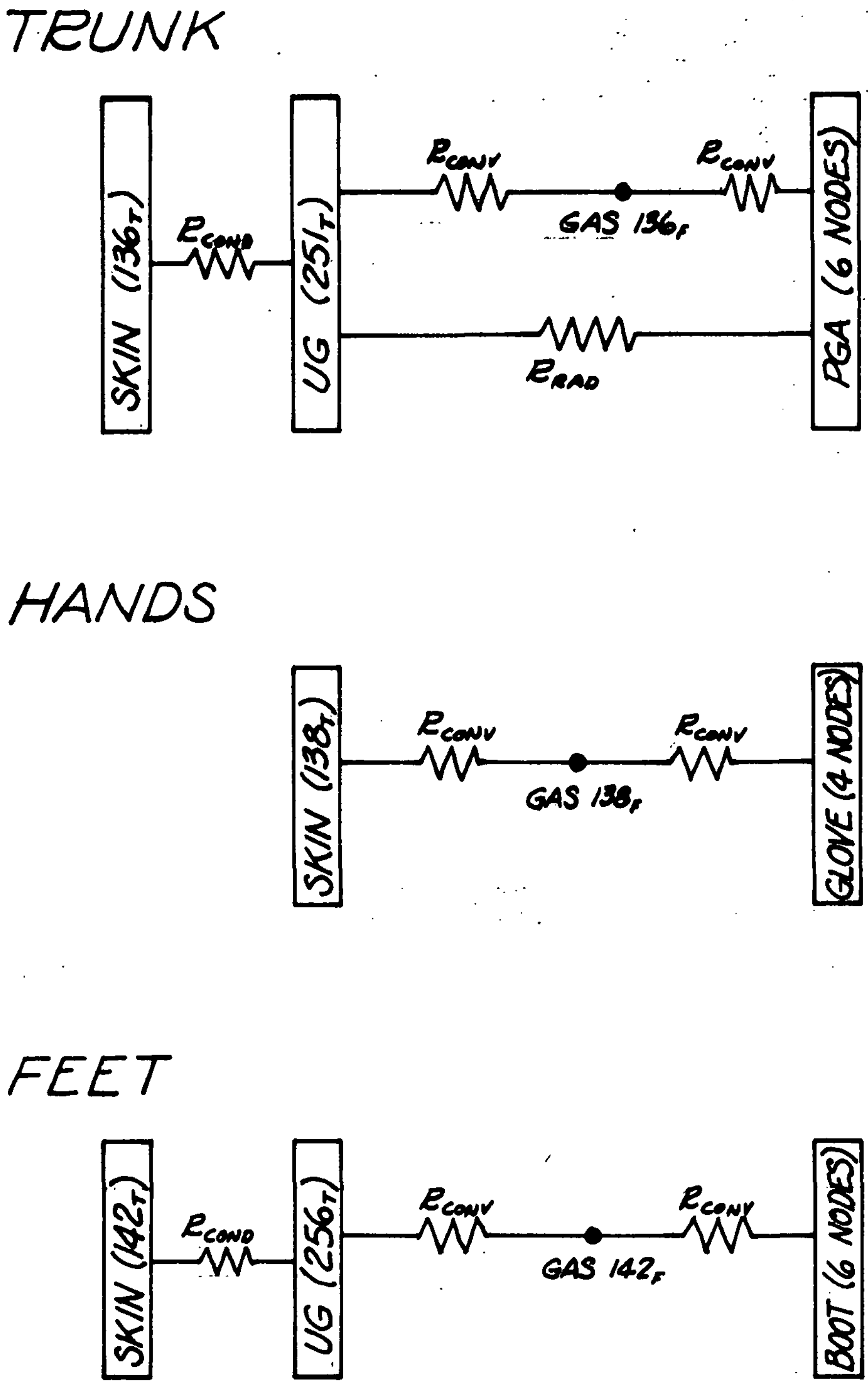


FIGURE 3-4 CREWMAN ENVIRONMENT INTERFACE MODEL

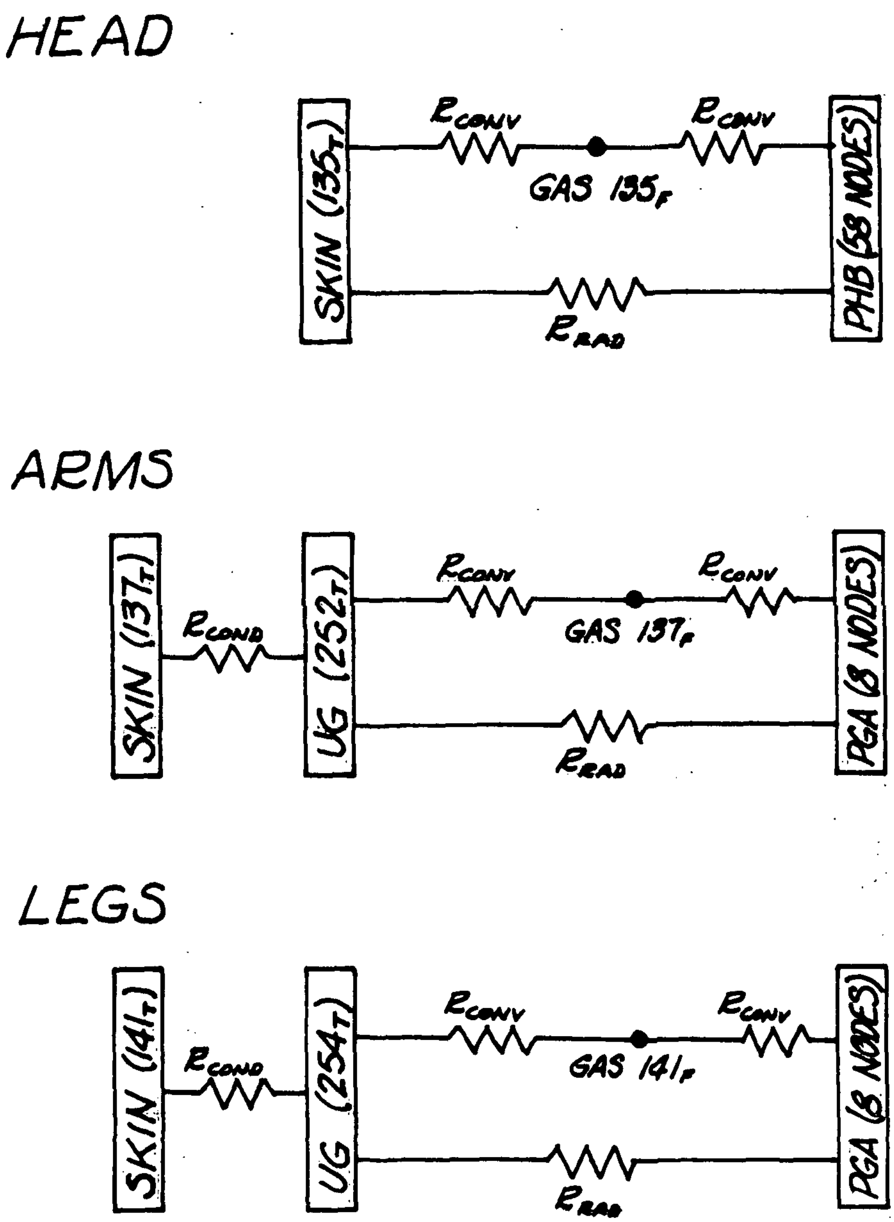


FIGURE 3-4 (CONT'D) CREWMAN ENVIRONMENT INTERFACE MODEL

All forty-one man temperatures, temperature averages of the skin and muscle plus eleven other variables to determine the man's relationship to his environment are output at each print interval.

3.7 Component Characterization

To simulate the ventilation oxygen system and the OPS, individual components must be simulated in order to calculate system pressure drop and temperature rise. The portion of the vehicle coolant loop of interest involves only a section of three eighths inch (outside diameter) tubing which requires no special characterization.

3.7.1 Oxygen Restrictor

The restrictors are small diameter tubes (.019 inch inside diameter) which are wrapped around the 3/8 inch vehicle coolant line. Most of the system pressure is dropped across the restrictors. Figure 3-5 presents the performance of the three restrictors in parallel for a supply pressure of 865 psia.

3.7.2 Extravehicular/Intravehicular Activity Panel

The panel is composed of three major components: shut-off valve, pressure regulator, and quick disconnect. Only the pressure regulator requires special handling with respect to component characterization. The pressure regulator drops the upstream pressure to 100 $\pm$ 5 psig for the normal range of flowrate (10 to 12 lb/hr). Logic is written into program which changes the downstream regulator pressure to a user input value as long as the upstream pressure is greater than the input value. If the upstream regulator pressure is less than the control unit value requested by the user, the regulator is full open and does not control the downstream regulator pressure. When the regulator is full open, a small pressure drop ($\approx$ 3 psi) occurs across the regulator and is incorporated in the pressure regulator simulation.

3.7.3 Umbilical

The umbilical delivers the oxygen to the SCU after pressure regulation at the EV/IV panel (Section 3.7.2). Since the oxygen supply system is a blowdown system, a return oxygen hose is not required. The umbilical includes electrical cables which are placed around the oxygen hose and then the entire umbilical is covered with multilayer insulation. A tether is incorporated in the umbilical to carry all longitudinal loads. The oxygen hose is 0.9 inch outside diameter and 0.375 inch inside diameter.

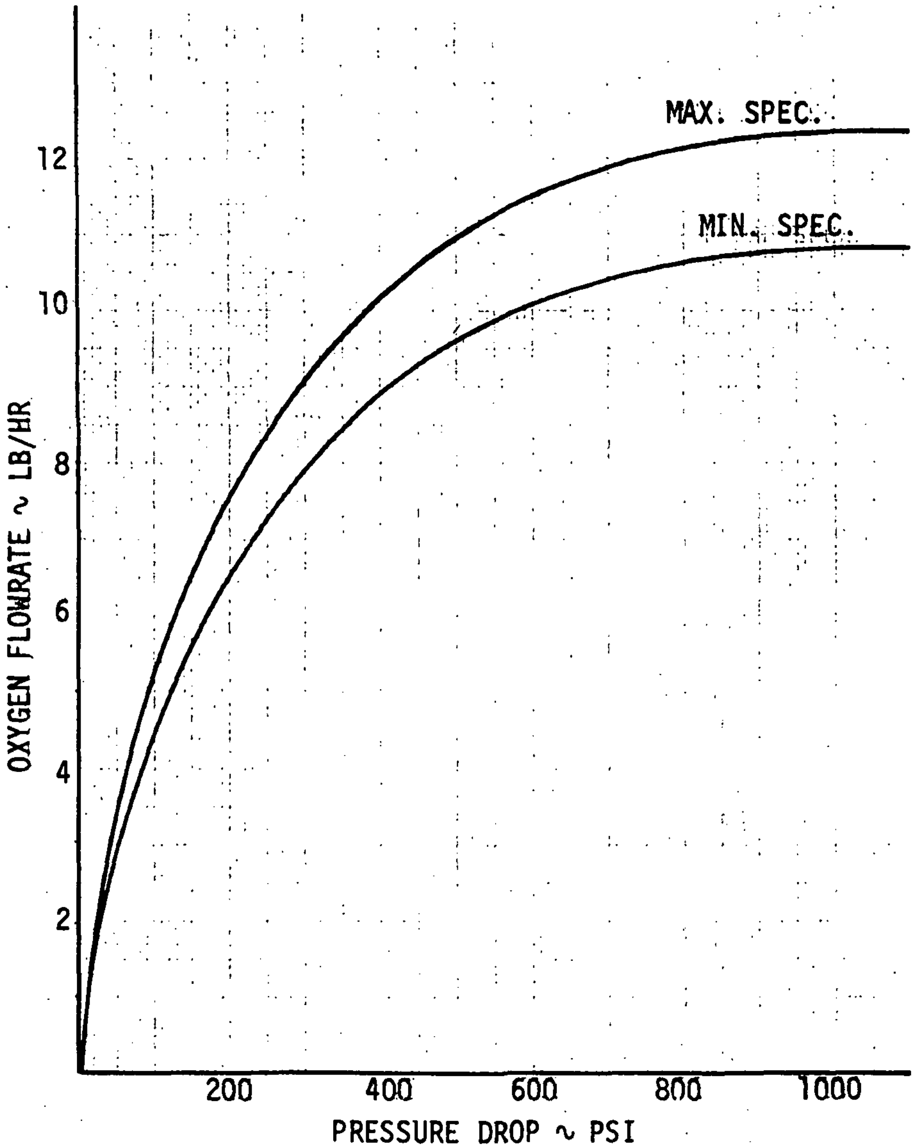


FIGURE 3-5 OXYGEN RESTRICTOR PERFORMANCE

3.7.4 Suit Control Unit (SCU)

The SCU consists of a filter, a shutoff valve, an orifice, a suit connector, and two pressure switches. Flow from the umbilical is metered by the 0.04 to 0.043 inch diameter SCU orifice. The pressure switches are placed one on either side of the SCU orifice to warn the crewman of decreasing suit pressure or decreasing purge flow pressure.

3.7.5 Suit

The crewman's space suit is composed of the pressure garment assembly (PGA) and the integrated thermal/meteoroid garment (ITMG). The flow-splits in the PGA for the suited modes were furnished in the subroutines of the 41-node metabolic man program (NASA) and were used without change. Likewise, the convection and radiation heat transfer between the suit wall and crewman's undergarment are calculated as in the NASA program with provisions added to handle multi-node suit areas around a single skin compartment.

The PGA may be assumed to have leakage by inputting a curve of leakage rate versus time. Gas leakage leaves the PGA and the gas loop at the outlet gas connector at a humidity which is the average of the inlet and outlet humidities of the suit gas. Pressure drop through the suit is calculated using the following equation:

$$\Delta P = C_7 \frac{T_{in}}{P_{in}} (\dot{W})^{N_7}$$

where ΔP = the pressure drop through the suit, psi

T_{in} = gas temperature into the suit, ^{o}R

P_{in} = gas system pressure into the suit, psia

$\dot{W}$ = gas flowrate, LB/hr

Suggested values for C_7 = 1.062E-5 and N_7 = 1.862

3.7.6 Pressure Control Valve

A pressure control valve (PCV) is used to control the suit pressure during normal operation of primary oxygen supply system. The PCV incorporates a manual shut-off to override the valve, if desirable. In the event the PCV fails to open, the suit to ambient pressure difference will remain above 3 psi for minimum umbilical flow (10 lb/hr).

3.7.7 Oxygen Regulator

The EMU has two oxygen regulators in which the oxygen is expanded to a lower pressure. The expansion process cools the gas which in turn cools

the regulator. The temperature and pressure into the regulator are known and used to interpolate on a curve to find the enthalpy of the gas entering the regulator. An isoenthalpic expansion is assumed as the gas enters the regulator. The user inputs the heat transfer coefficient between the expanded gas and the regulator.

3.7.8 Oxygen Purge System (OPS) Heater

The heater, heater controller, and battery were deleted in OPS's assembled for Apollo 14 and subsequent flights. Logic to analyze the heater was retained but the data tape was modified to reflect the deletion. The following paragraph documents the heater as originally used.

The OPS heater is located upstream of the OPS oxygen regulator and preheats the oxygen before it is expanded in the regulator. Downstream of the regulator is a fluid sensor which determines when the heater is on. The user inputs the heat transfer coefficient between the gas and heater element and the heater power. Two sensor set point temperatures (TSEN1, TSEN2) are input. If the sensor temperature is below TSEN1 and increasing, heater power will be maintained at a constant value (user input) until the TSEN2 valve is exceeded. If the sensor temperature is above TSEN2 and decreasing, the heater remains off until the sensor temperature drops below TSEN1. The heater may be on or off if the sensor temperature is within the TSEN1 to TSEN2 band as explained above.

3.8 Consumables Characterization

The simulator monitors the depletion of the oxygen in the OPS tank. OPS oxygen is the only consumable of interest during a Command Module EVA. The user inputs the initial mass of the oxygen and the simulator substracts the quantity used and outputs the quantity remaining. The oxygen and oxygen bottle are entered as structure lumps with the heat transfer coefficient, initial pressure, and volume input. Bottle pressure is updated each iteration to account for temperature and/or mass changes. Mass of the oxygen initially in the OPS oxygen bottles is input as the product of the mass times the specific heat as described on the structure type data card for the oxygen. In the baseline thermal model, the initial mass of the oxygen is split equally between the two OPS bottles. An average temperature out of the OPS bottles is used since the OPS bottles blowdown simultaneously.

3.9 Oxygen Bottle Blowdown Characterization

The EMU OPS contains two spherical oxygen bottles which comprise an emergency or purge supply. The flowrate from the bottles is known as a function of time. The OPS oxygen flowrate is determined by a purge relief valve placed in the right hand side, oxygen, suit outlet connector.

The increase in stored energy of the gas is, semantically:

$$\begin{bmatrix}\text{Increase in}\\ \text{Stored Energy}\\ \text{of Gas in Bottle}\end{bmatrix} = \begin{bmatrix}\text{Energy Added to}\\ \text{Gas From Bottle}\end{bmatrix} - \begin{bmatrix}\text{Energy of Gas}\\ \text{Leaving Bottle}\end{bmatrix}$$

Using the above equation the temperature of the gas is calculated. This temperature and the last bottle pressure value is used to interpolate on a compressibility factor curve. The gas temperature and mass remain constant while the pressure and compressibility factor are interated until the pressure on successive iterations is within DPTOL.

The heat transfer coefficient inside each oxygen bottle is input and is constant for a mission.

3.10 Heat Leak Calculation

The EMU simulator has the capability of calculating the heat flux between any two nodes. Data input format (see Section 5.7.6) permits the user to group pairs of nodes to create the desired control volume. Figure 3- 6 presents a typical heat leak model to calculate the heat transferred across the boundary of a control volume. The input data would be set up with one group consisting of five heat leak paths. Semantically, the analysis per heat leak path is:

$$\begin{bmatrix}\text{Energy Entering}\\ \text{The}\\ \text{Control Volume}\end{bmatrix} = \begin{bmatrix}\text{Energy Conducted}\\ \text{To Node j}\\ \text{From Node K}\end{bmatrix} + \begin{bmatrix}\text{Energy Radiated}\\ \text{To Node j}\\ \text{From Node k}\end{bmatrix} - \begin{bmatrix}\text{Energy Stored}\\ \text{By Node j}\end{bmatrix}$$

Notice that the heat leak into the control volume (or from node k to node j) is assumed positive.

In the EMU simulator, heat leak groups for the Lunar Extravehicular Visor Assembly (LEVA), Pressure Garment Assembly (PGA), and several other

components of interest are set up. There is no program limit on the number of groups or the number of heat leak paths (node pairings) per group. One restriction is made; and it requires the first group to be the LEVA heat leak group. This requirement arises because the LEVA visor material transmits solar wavelength energy through "node j". The energy entering the LEVA through the visors is automatically added to the first heat leak group. There are other unique features associated with the visor analysis as explained in Section 3.12.

To identify a heat leak path the user enters the two nodes (j and k) and a connection number for conduction and radiation between nodes j and k. The connection number is determined from node j lump card (tube or structure) by counting, from left to right, the "to" lumps to node k. It is necessary that the user know which node j to node k connection is the conduction connection and which is radiation to properly assign the connection numbers in the heat leak data. A check of the type data for node j will aid the user in establishing the kind of connection made to node j. Notice, when node j is connected to node k by conduction and radiation, node k will appear twice as a "to" lump on the node j lump card. Therefore the connection numbers for a node pair in the heat leak data connot be equal.

3.11 Heat Storage Calculation

The EMU simulator has the capability of calculating the energy stored by a node from initial condition (i.e., initial temperature on lump card) to some later time. Net heat stored by a node at time, τ, is calculated by the following equation:

$$Q_{stored,j} = WC_{j,\ at\ \tau}\,(T_{j,\ at\ \tau} - T_{j,\ at\ \tau=\tau_i})$$

If the computer run is interrupted and restarted, the initial temperature used in the above equation is identical to the temperature input on the tube or structure lump card. The WC product is the current value including any adjustments prescribed by the Time-Variant Mass Data and/or the specific heat curve data. The user inputs the node number and the applicable identifying code (see Section 5.7.7) of the nodes for which heat storage calculations are desired. A single value of heat storage will be output when several nodes are grouped together. There is no program limit on the number of groups or the number of nodes per group that may be input.

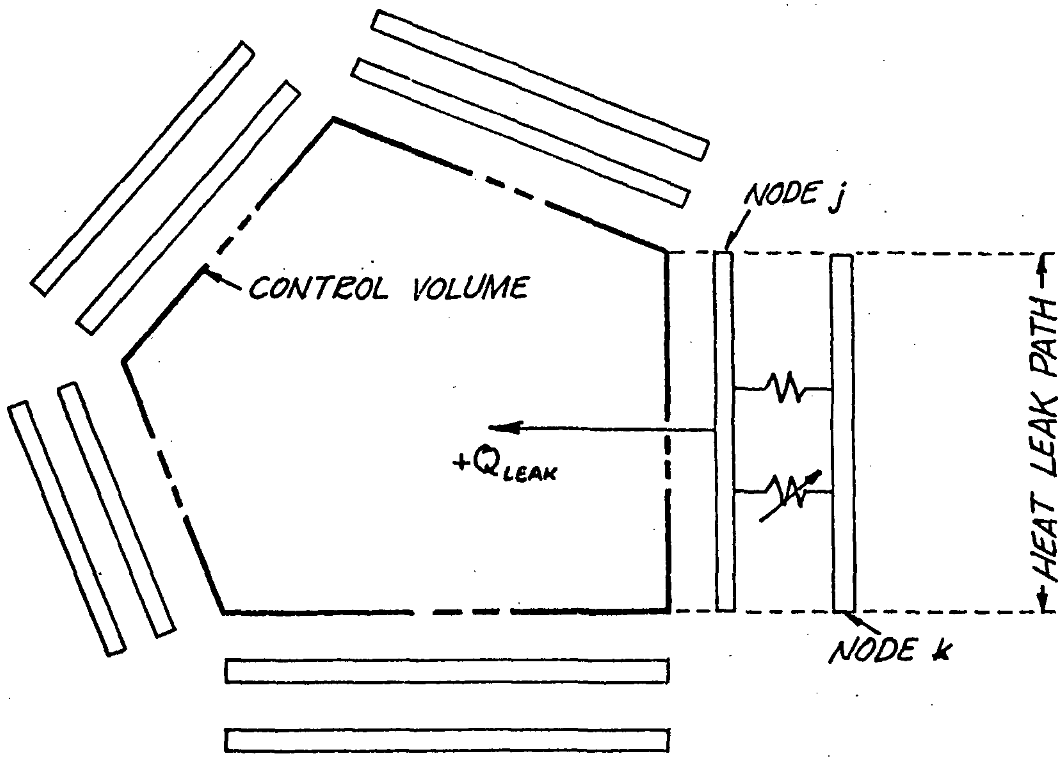


FIGURE 3- 6 TYPICAL HEAT LEAK MODEL

3.12 LEVA Visor Analysis

The crewman's face is protected by two retractable visors and a pressure bubble. The retractable visors have special coatings which transmit radiation in the visible spectrum and block infrared radiation. A visor analysis is required to calculate the fraction of external incident energy absorbed by each visor and the crewman's face. The analysis is complicated by the fact that the visors may be positioned in three unique configurations (see Figure 3- 7): both visors down, sun visor up, and both sun visor and impact visor up.

The fraction of incident energy absorbed by a visor surface can be determined from coating properties and has been done by A. J. Chapman as recorded in informal documentation received October 1966. Chapman numbers the surfaces 1 to seven with one being the crewman's face and seven, the outer surface of the sun visor (Figure 3- 7). This same convention is followed below as well as Chapman's notation of the energy fraction. $F_i^{(k)}$ refers to the fraction of the external incident radiation on the ith surface for the kth visor configuration. To shorten the equations we define R_{ij} as the fraction, $1/(1-\rho_i\rho_j)$, where ρ is the solar reflectivity and i and j are visor surfaces.

Each node on the visor and helmet surfaces is assigned a position number; one to the total number of nodes on the visor and helmet surfaces. In addition to a position number, the user inputs a position type (see Section 5.7.8) to associate the correct surface properties with the visor, helmet, and face nodes. The visor analysis is a two band spectral distribution analysis with the separation point between solar and infrared radiation established by the flux data input from the Environmental Heat Flux Routine (Reference 12).

With both visors retracted - n = 1

$$F_1^{(1)} = \tau_{23}\, R_{12};\ F_2^{(1)} = \rho_1\, F_1^{(1)}\ ;\ \ F_3^{(1)} = 1.$$

Transmissivity, τ_{23}, is the solar transmissivity of the pressure bubble and, in Chapman's development of the $F_i^{(n)}$, the assumption was made that $\tau_{ij} = \tau_{ji}$.

With the impact visor down and sun visor up - n = 2

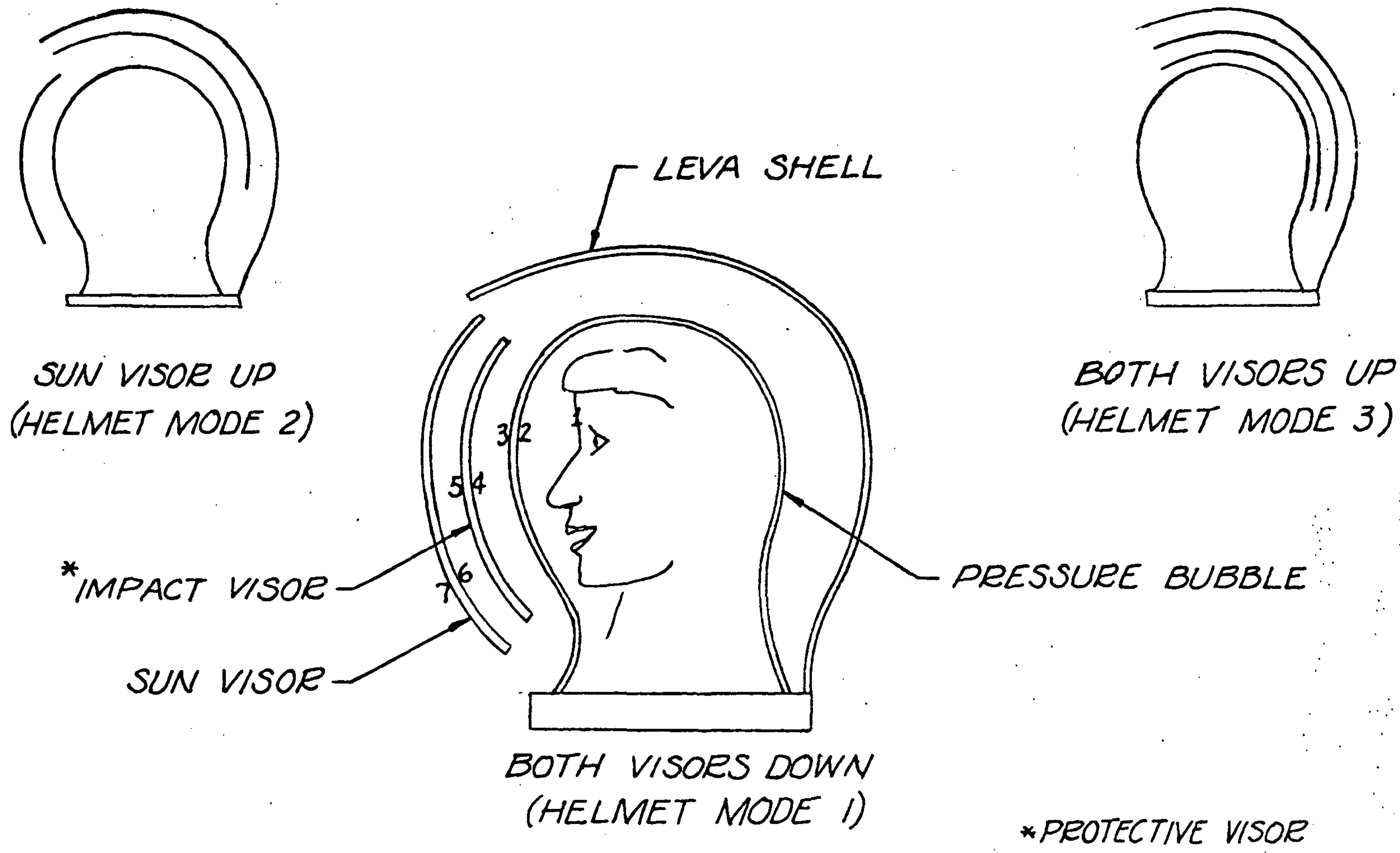


FIGURE 3- 7 LUNAR EXTRAVEHICULAR VISOR ASSEMBLY (LEVA)

$$F_1^{(2)} = F_1^{(1)} F_3^{(2)}$$

$$F_2^{(2)} = F_2^{(1)} F_3^{(2)}$$

$$F_3^{(2)} = \frac{\tau_{45} \qquad R_{34}}{1-\rho_4\tau_{23}R_{34}F_2^{(1)}}$$

$$F_4^{(2)} = \rho_3\, \tau_{45}\, R_{34} \;+\; \tau_{23}\, R_{34}\, F_2^{(1)}\, F_3^{(2)}$$

$$F_5^{(2)} = 1.$$

With sun visor down - n = 3

$$F_1^{(3)} = F_1^{(2)} F_5^{(3)}$$

$$F_2^{(3)} = F_2^{(2)} F_5^{(3)}$$

$$F_3^{(3)} = F_3^{(2)} F_5^{(3)}$$

$$F_4^{(3)} = F_4^{(2)} F_5^{(3)}$$

$$F_5^{(3)} = \frac{\tau_{67} \qquad R_{56}}{1-\rho_6\tau_{45}R_{56}F_4^{(2)}}$$

$$F_6^{(3)} = \rho_5\, \tau_{67}\, R_{56} \;+\; \tau_{45}\, R_{56}\, F_4^{(2)}\, F_5^{(3)}$$

$$F_7^{(3)} = 1.$$

3.13 Local Temperature Perturbation (LTP) Calculation

The simulator has the capability of calculating the effect of a perturbed suit condition on the crewman. By perturbed suit condition is meant the local compression of the suit against the crewman due to sitting, kneeling, gripping with the gloves, etc. The purpose of the capability is to determine crewman comfort (skin temperature below threshhold of pain) when engaged in any activity which involves "shorting" the suit multilayer insulation. Section 5.7.5 details the input data for local temperature perturbation calculations. It is important to remember when preparing data for the LTP model that this model is completely independent of the basic EMU model and has no feedback

to it. Notice should be made that LTP model lump numbers are described in the regular data and that Section 5.7.5 provides additional information which identifies certain lump numbers as LTP lump numbers. All LTP model fluid (gas) lumps must be input in tube 21 which satisfies the data input requirement for a flow tube but the order of fluid lumps in tube 21 is arbitrary.

3.14 Thermal Data Options

The simulator has several unique data options which are required to describe the thermal model or provide the user flexibility desired.

3.14.1 Suit, Gloves, and EV Boots Node Identification

This option is required to simulate the suit donning and doffing procedures by the crewman in the Command Module (CM). Table 3-1 defines the EMU configuration modes the user may select to include in the mission analysis. Each category of nodes is identified either directly or by the process of elimination. The pressure bubble nodes are identified through Helmet and Visor Data and with the suit, gloves and boots identified all other nodes are considered to be in the remaining category of Oxygen Purge System (OPS) and Remote Control Plate. All node connections are made in the baseline thermal model necessary to analyze EMU Configuration Mode 1. When other modes are specified the simulator stops analyzing components designated as "off" and no temperature update of nodes identified with "off" components occurs until a mode is again selected in which those components are designated as "on".

3.14.2 Configuration-Associated Node Identification

This option is similar to the one discussed above but requires more input data to establish the same configuration. The user may view this option as an override of the configurations specified by Table 3-1. As an example of how this option may be used, consider Mode 8 which specifies analysis of the crewman in his shirtsleeves only. To obtain the effect of an enclosure such as the CM cabin walls on a shirtsleeves crewman, structure nodes representing the wall can be input in the regular data and then associated with Configuration Mode 8.

3.14.3 Heat Flux Curve Assignment

The simulator uses the Environmental Heat Flux Routine (EHFR) described in Reference 11 as a source of input flux data representing various lunar surface topology. The EHFR has geometric heat flux models of the EMU and the Scientific Instruments Module (SIM) Bay which are consistant with the surface areas

TABLE 3-1 EMU CONFIGURATION MODES

MODES	PLSS OPS & RCU	ITMG SUIT	GLOVES	EV BOOTS	PRESSURE BUBBLE	TYPE ACTIVITY	NOTES
± 1	ON	ON	ON	ON	ON	EV	LEVA ON + PGA FLOW DIV. VLV.,HOR.(IV) — PGA FLOW DIV. VLV.,VERT.(EV)
± 2	ON	ON	ON	ON	ON	IV	LEVA MAY BE ON OR OFF + OR — INDICATES PGA FLOW SPLIT
± 3	ON	ON	OFF	ON	ON	IV	+ OR —INDICATES PGA FLOW SPLIT, PGA AND EV GLOVES REMOVED TOGETHER
4	ON	ON	OFF	ON	OFF	IV	
5	OFF	ON	OFF	ON	OFF	IV	
6	OFF	ON	OFF	OFF	OFF	IV	
± 7	OFF	ON	ON	OFF	ON	IV	
8	OFF	OFF	OFF	OFF	OFF	IV	PGA OFF - SHIRTSLEEVES

of the simulator baseline thermal model. Section 5.7.1, Cards 4 and 5 give instructions on the manipulation of the EHFR generated flux data actually creating heat flux curves. Although the curves have been created and are available, heat flux curve assignment data is required to apply the flux to a particular thermal model node. The EHFR outputs a contact temperature which represents the lunar surface temperature and this temperature is prescribed to a baseline thermal model node which is in contact with the extravehicular boot soles. All EHFR input data is assigned through the data described in Section 5.7.11.

3.14.4 Prescribed Wall Temperature Data

The simulator has two types of prescribed wall temperatures excluding the contact temperature discussed in Section 3.14.3. These prescribed temperatures are designated as type numbers 10 and 11 in Sections 5.7.12 and 5.7.15. Type 10 is used to create a "deep space" node held constant as -459.69^{O}F or other prescribed temperatures where the entire curve can be put on the data tape. Type 11 is used to input SIM bay prescribed temperatures either the complete curve or segments of a large curve contained on an independent input tape. Variable NPRTCD on Card 2 (Section 5.7.1) designates how the SIM bay temperatures will be input. The simulator will interrogate NPRTCD and, if 1, will read additional SIM bay temperature data when the largest time of the segment of the curve in the computer is less than mission time.

3.14.5 Time Variant Node Data

Time variant data allows the user to vary with time the mass of a node and/or the connection between two nodes. This data is a multiplying factor applied after variations in specific heat and thermal conductivity have been taken into account. The time variant mass data is straight forward with the user identifying the node and the controlling curve number. If a connection between two nodes is to be varied, the user must identify the "from" node and specify a connection number. The connection number for a node varies from 1 to the number of "to" nodes listed in the tube and structure lump cards for the node. This option applies to both conduction and radiation connections for tube and structure nodes.

4.0 BASELINE THERMAL MODEL

A baseline thermal model was created in conjunction with the EMU simulator and contains the following items:

1. ITMG - Integrated Thermal/Meteoroid Garment (A7LB)
2. PGA - Pressure Garment Assembly
3. Boots - Lunar EVA Configuration
4. Gloves - Extravehicular Configuration
5. LEVA - Lunar Extravehicular Visor Assembly
6. OPS - Oxygen Purge System
7. CREWMAN - 41 Node Man (Ref. 11)
8. SIM Bay - Scientific Instruments Module Bay

The model is composed of the three types of nodes described in Section 3.1. The number of flow tubes in the simulator is 21. The simulator is programmed to expect the number of tubes indicated above and program modifications are required to change the tube arrangement. Although the user is limited in the extent to which he can change the basic thermal model, important options are open as to the fineness of the model breakdown and the amount and type of data output.

The ITMG, PGA, Boots, and Gloves were broken up into 96 surface nodes and 5 nodes through the thickness. Figure 4-1 and 4-2 show the surface nodes as numbered in the baseline thermal model and a typical cross-section of the suit. Table 4-1 presents the complete suit node numbering with the "EXTERIOR ITMG NODE" column corresponding to the nodes of Figure 4-1. The multilayer insulation has the same fineness of nodal breakdown as the exterior suit surface, but the three interior node layers have fewer nodes as indicated by the brackets in Table 4-1 connecting two or more insulation nodes to an "INTERIOR ITMG NODE". Figure 4-1 presents a surface area lumping of a more detailed geometric suit model found in Reference 13. Conductance values for the

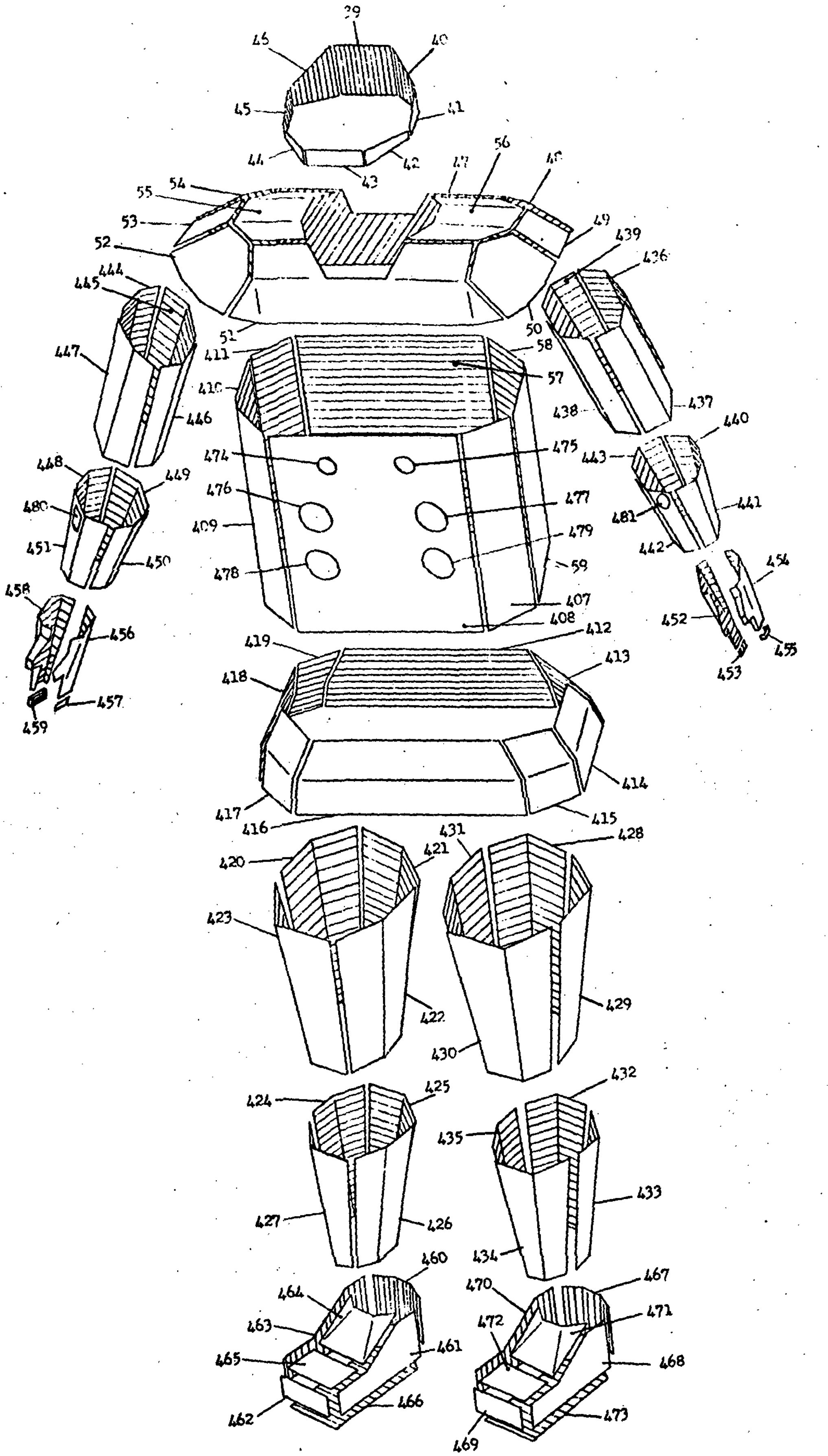


FIGURE 4-1 SUIT, BOOTS, AND GLOVES BASELINE THERMAL MODEL

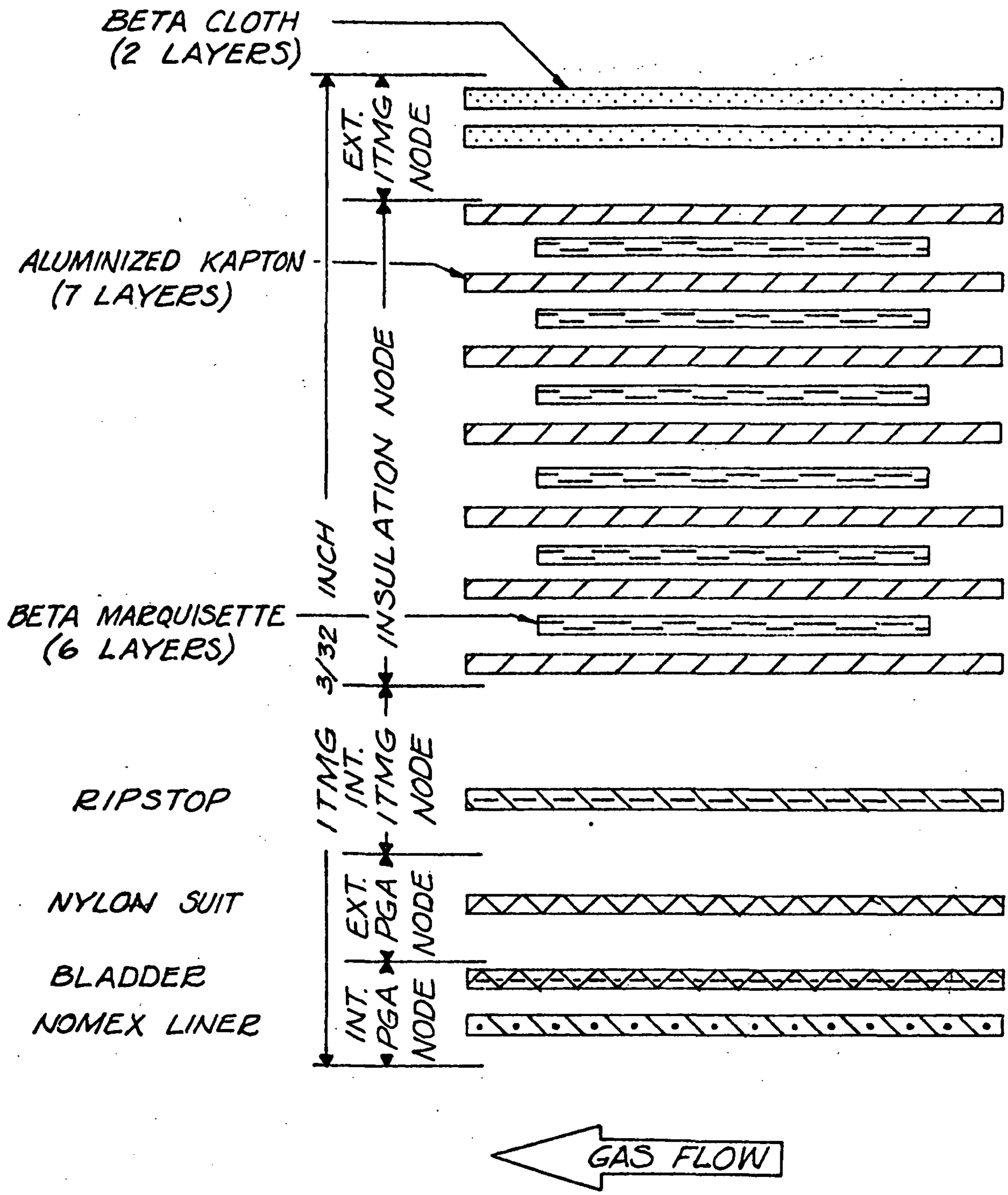


FIGURE 4-2 TYPICAL SUIT CROSS-SECTION

TABLE 4-1

NODAL NUMBERING THROUGH SPACE SUIT

EXTERIOR ITGM NODE	INSULATION NODE	INTERIOR ITMG NODE	EXTERIOR PGA NODE	INTERIOR PGA NODE
39 40 41	60 61 62	81	217	145
42 43 44 45	62 63 64 65 66	82	218	146
46	66 67	81	217	145
47 48	68 69	83	219	147
59	69 70	89	225	135
50	70 71	91	227	155
51 52	71 72 73	84	220	148
53	73 74	92	228	156
54	74 75	90	226	154
55 56	75 76 77	83	219	147
	76 77	84	220	148
57 58 59	78 79 80	86	222	150
407 408 409 410	80 482 483 484 485	85	221	149
411	485 486	86	222	150
412 413 414	487 488 489	88	224	152
415 416 417 418	489 490 491 492 493	87	223	151
	493	88	224	152

TABLE 4-1(CONTINUED)

EXTERIOR ITMG NODE	INSULATION NODE	INTERIOR ITMG NODE	EXTERIOR PGA NODE	INTERIOR PGA NODE
419	494	88	224	152
420	495	549	561	229
421	496			
422	497	100	236	227
423	498			
424	499	553	565	233
425	500			
426	501	551	563	231
427	502			
428	503	550	562	230
429	504			
430	505	101	237	228
431	506			
432	507	554	566	234
433	508			
434	509	552	564	232
435	510			
436	511	89	225	135
437	512	91	227	155
438	513			
439	514	89	225	135
440	515	94	230	155
441	516	96	232	160
442	517			
443	518	94	230	155
444	519	90	226	154
445	520			
446	521	92	228	156
447	522			
448	523	93	229	157
449	524			
450	525	95	231	159
451	526			
452	527	99	235	164
453	528			
454	529	98	234	163
455	530			
456	531	97	233	162
457	532			
458	533	624	625	161
459	534			
460	535	557	569	237
461	536	555	567	235
462	537			
463	538			
464	539			
465	540			
466	541	559	571	239
467	542	558	570	238

TABLE 4-1(CONTINUED)

EXTERIOR ITMG NODE	INSULATION NODE	INTERIOR ITMG NODE	EXTERIOR PGA NODE	INTERIOR PGA NODE
468	543			
469	544			
470	545	556	568	238
471	546			
472	547			
473	548	560	572	240
			474	241
BIB DATA, IF BIB IS WORN			476	242
			477	243
			478	244
			479	161
480	573	574	575	245
481	576	577	578	246

multilayer buildup were generated by the Lockheed Electronics Corporation under the direction of the Crew Systems Division - Manned Spacecraft Center and edited into the baseline thermal model data tape. These conductances were based on data obtained from manned and unmanned suit tests conducted by NASA at the Manned Spacecraft Center.

The LEVA thermal model consists of the sun visor, protective visor, pressure bubble, and LEVA shell as presented in Figures 4-3 through 4-7. Tables 4-2 and 4-3 are to be used in conjunction with Figures 4-3 and 4-4 respectively in interpreting the thermal model data. The simulator allows the user to specify visor configuration changes throughout the mission. The three helmet modes illustrated in Figure 3-7 require connections between nodes peculiar to an individual helmet mode, therefore for the sun visor (SV) and protective visor (PV) there is a set of nodes for each helmet mode. When the helmet is in MODE 1, only the nodes corresponding to this mode for the SV and the PV are analyzed; however the other nodes are updated each iteration. A change to a different helmet mode changes the set of nodes being analyzed and the initial temperatures for the new modes are the last temperatures calculated for MODE 1 because of the continuous iteration update. A similar discussion applies when the helmet mode is begun in MODE 2 or MODE 3.

The LEVA shell is divided into two layers thus the node numbering in Figures 4-5 and 4-6. The exterior layer of the LEVA shell thermal model is the beta cloth cover while the interior layer includes the multilayer insulation and the polycarbonate inner shell. There is a single set of shell nodes for the three helmet modes. The surface area nodal breakdown is a modified version of that found in Reference 13. Nodes near the side of the helmet were increased in area and an additional row of nodes areas were created along the vertical centerline maintaining a constant number of nodes.

The pressure bubble is modeled as tube nodes because the inside of the bubble is in contact with the suit oxygen flow. A single set of nodes is used for all three visor configurations and the nodes are analyzed continuously as are the LEVA shell nodes. Two types of connections from the pressure bubble tube nodes must be made a function of the helmet mode. The first is the pressure bubble connection to space when both visors are up and the second is the connection to the interior layer of the LEVA shell when both visors are down. Since both the pressure bubble, the space node, and the LEVA

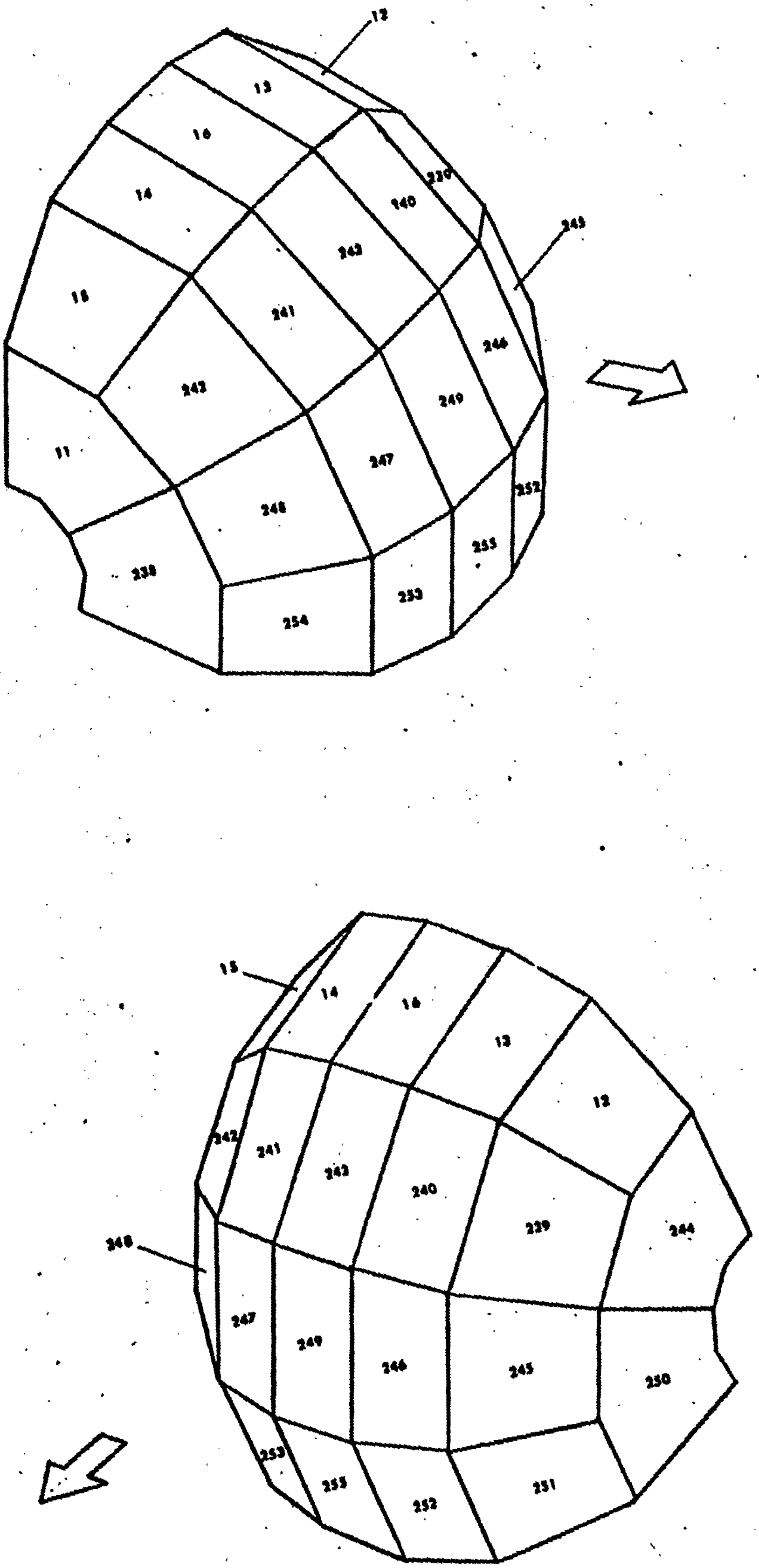


FIGURE 4-3 SUN VISOR THERMAL MODEL

TABLE 4-2

SUN VISOR NODE CORRESPONDENCE FOR HELMET MODES

MODE 1 (SUN VISOR DOWN)	MODE 2 (SUN VISOR ONLY UP)	MODE 3 (BOTH VISORS UP)
11	181	193
12	182	194
13	183	195
14	184	196
15	185	197
16	186	198
238	256	274
239	257	275
240	258	276
241	259	277
242	260	278
243	261	279
244	262	280
245	263	281
246	264	282
247	265	283
248	266	284
249	267	285
250	268	286
251	269	287
252	270	288
253	271	289
254	272	290
255	273	291

All nodes are structure nodes.

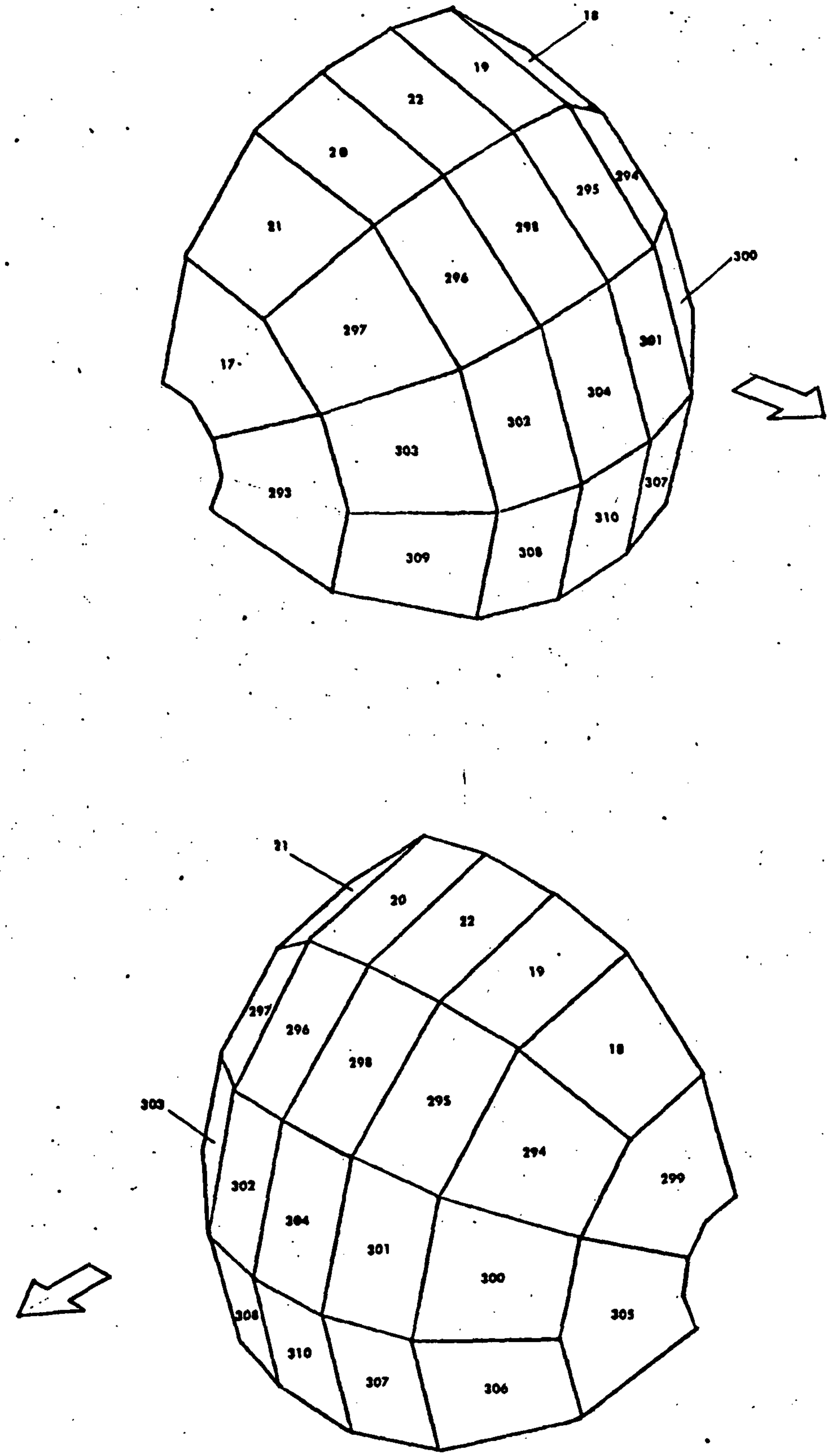


FIGURE 4-4 PROTECTIVE VISOR THERMAL MODEL

TABLE 4-3

PROTECTIVE VISOR NODE CORRESPONDENCE FOR HELMET MODES

MODE 1 (SUN VISOR DOWN)	MODE 2 (SUN VISOR ONLY UP)	MODE 3 (BOTH VISORS UP)
17	187	199
18	188	200
19	189	201
20	190	202
21	191	203
22	192	204
293	311	329
294	312	330
295	313	331
296	314	332
297	315	333
298	316	334
299	317	335
300	318	336
301	319	337
302	320	338
303	321	339
304	322	340
305	323	341
306	324	342
307	325	343
308	326	344
309	327	345
310	328	346

All nodes are structure nodes.

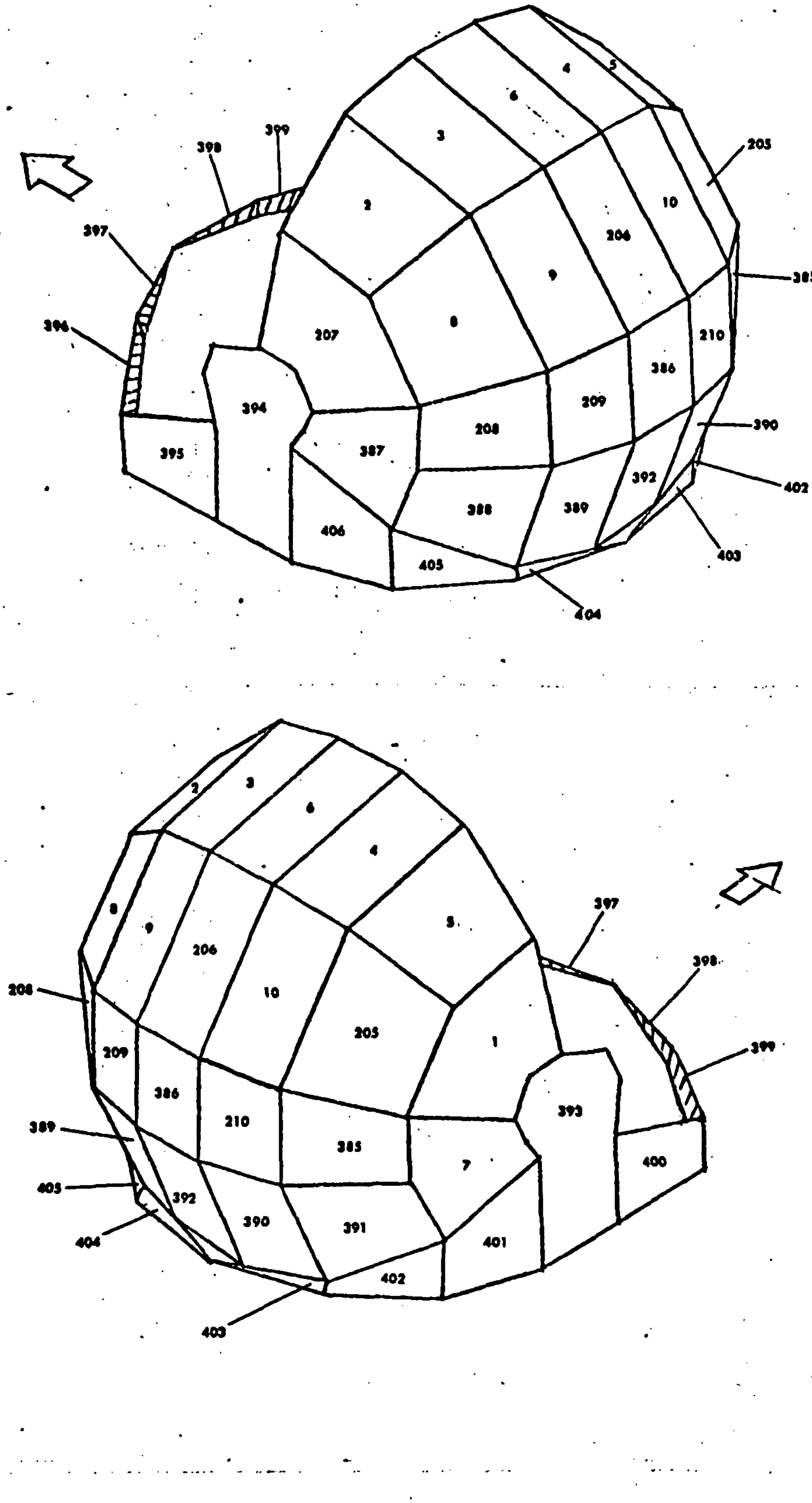


FIGURE 4-5 LEVA EXTERIOR THERMAL MODEL

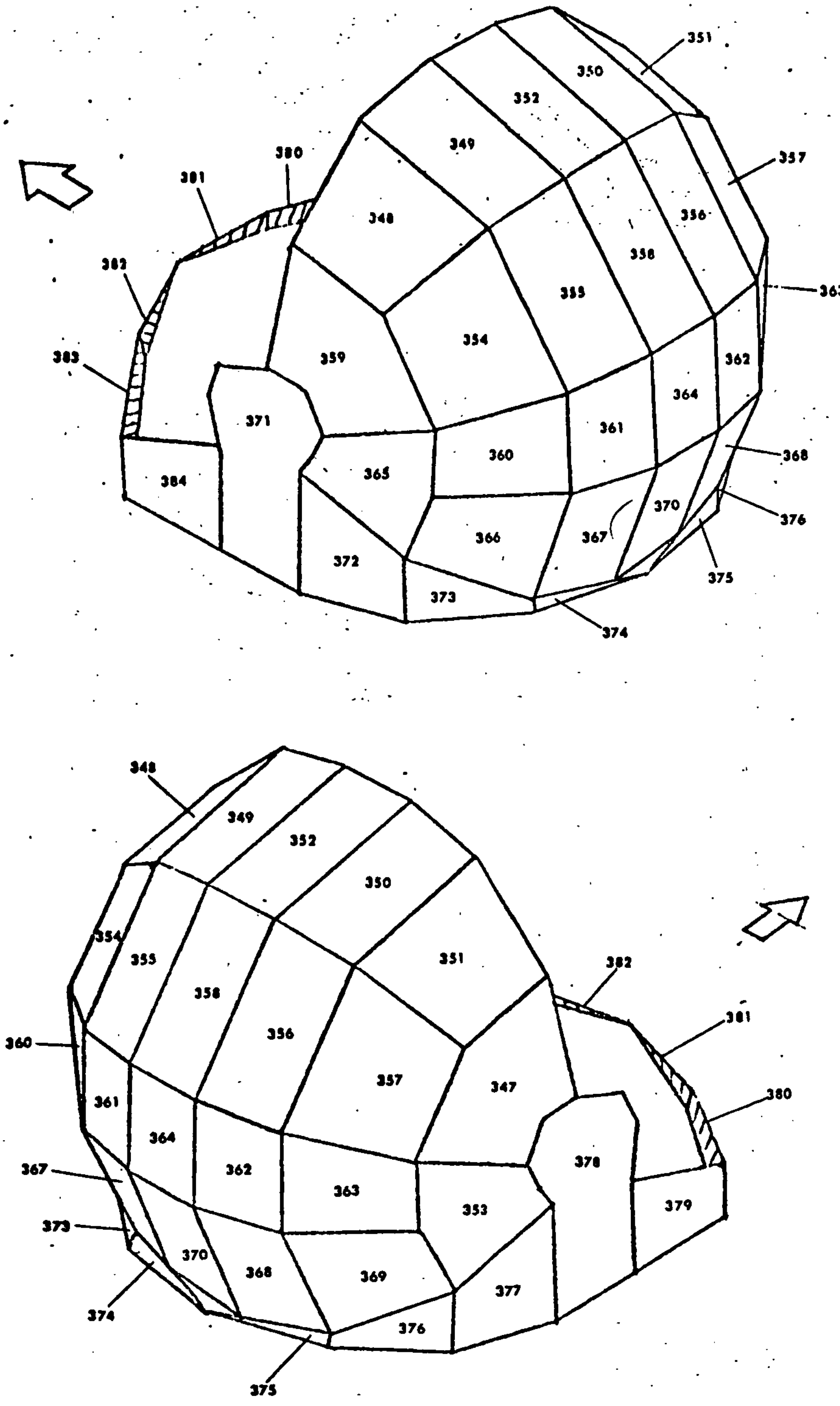


FIGURE 4-6 LEVA INTERIOR THERMAL MODEL

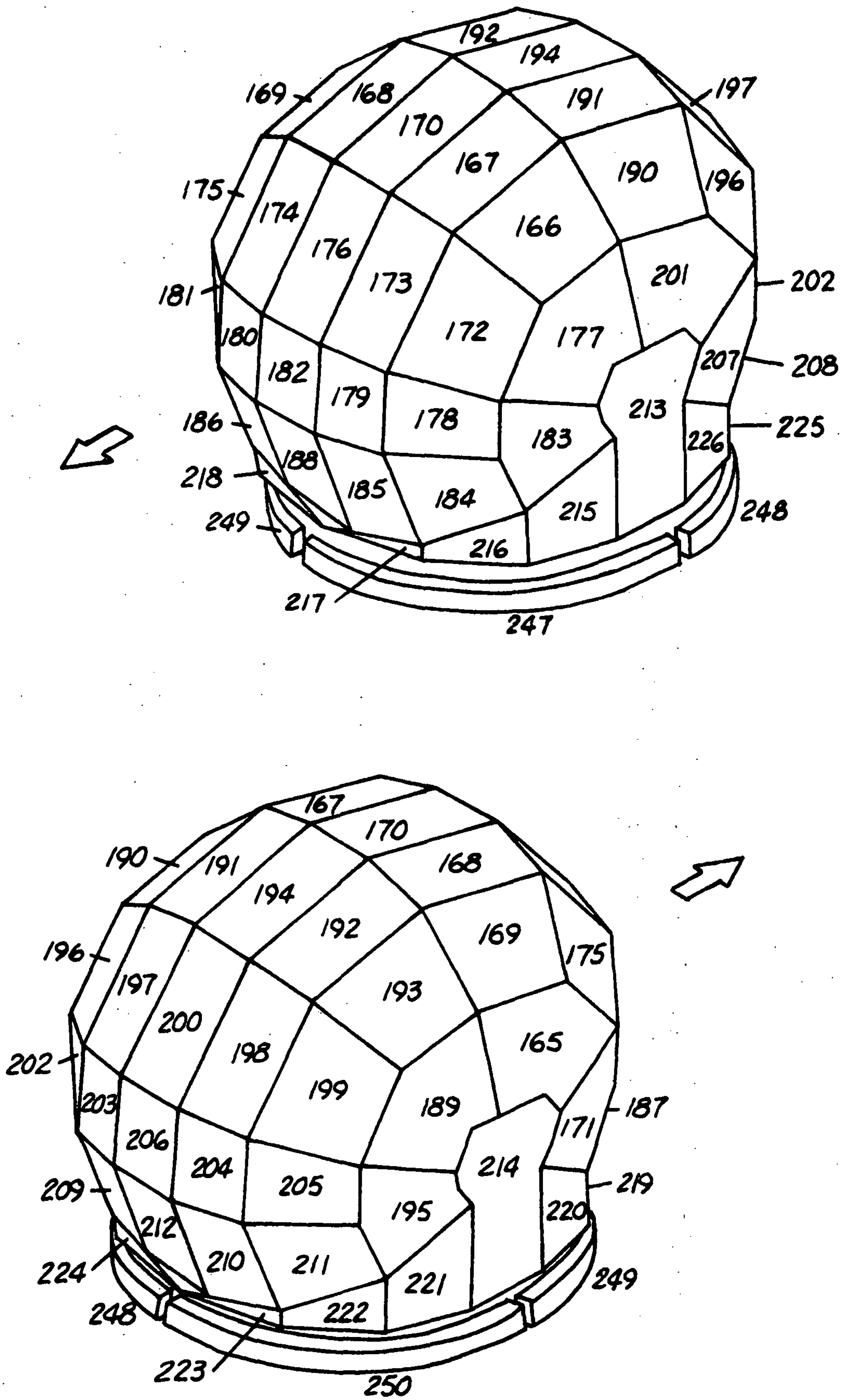


FIGURE 4-7 PRESSURE BUBBLE HELMET THERMAL MODEL

nodes are analyzed continuously, some method of making and breaking the connections described above is required. The simulator has such a capability called Time Variant Connections (Section 3.14.5) and it is used to coordinate pressure bubble connections with the visor connections which are determined by the set of visor nodes analyzed. No intermediate positions of the visors are allowed; a visor is either all the way up or all the way down. The LEVA has three sun shades which may be varied by the crewman through an infinite number of positions. These sun shades are not modeled in the baseline thermal model.

The OPS was modeled using the information from Reference 13 and the manufacturer's hardware drawings. The flow systems were broken up into fluid and tube nodes as shown in Figures 3-2 and 3-3. As a general rule, the system piping was broken at rubber splice joints and components. The fluid type data for the components was input so the regular pressure drop calculation would yield a zero delta P. Figure 4-8 shows the break-up of the OPS structure. Note the seven layers of multilayer insulation are modeled as two nodes through the thickness for the OPS thermal cover. Multilayer insulation conductances used in the baseline thermal model were obtained from correlations of unmanned space suit test conducted at NASA and LTV Aerospace.

The SIM bay is modeled with 56 structure nodes as shown in Figure 4-9. All SIM bay nodes are prescribed temperature nodes and are not analyzed transiently. The purpose of the SIM bay in the EMU simulation is to simulate the heat flux environment on the crewman as affected by the SIM bay emitting, reflecting and blocking energy. SIM bay temperatures were obtained from the results of the Apollo CSM thermal analysis and EHFR adiabatic temperature calculations. Each node has a prescribed temperature curve input in the curve data on the data tape. Appendix A provides additional descriptive information on the fluid, tube, and structure nodes discussed in this section.

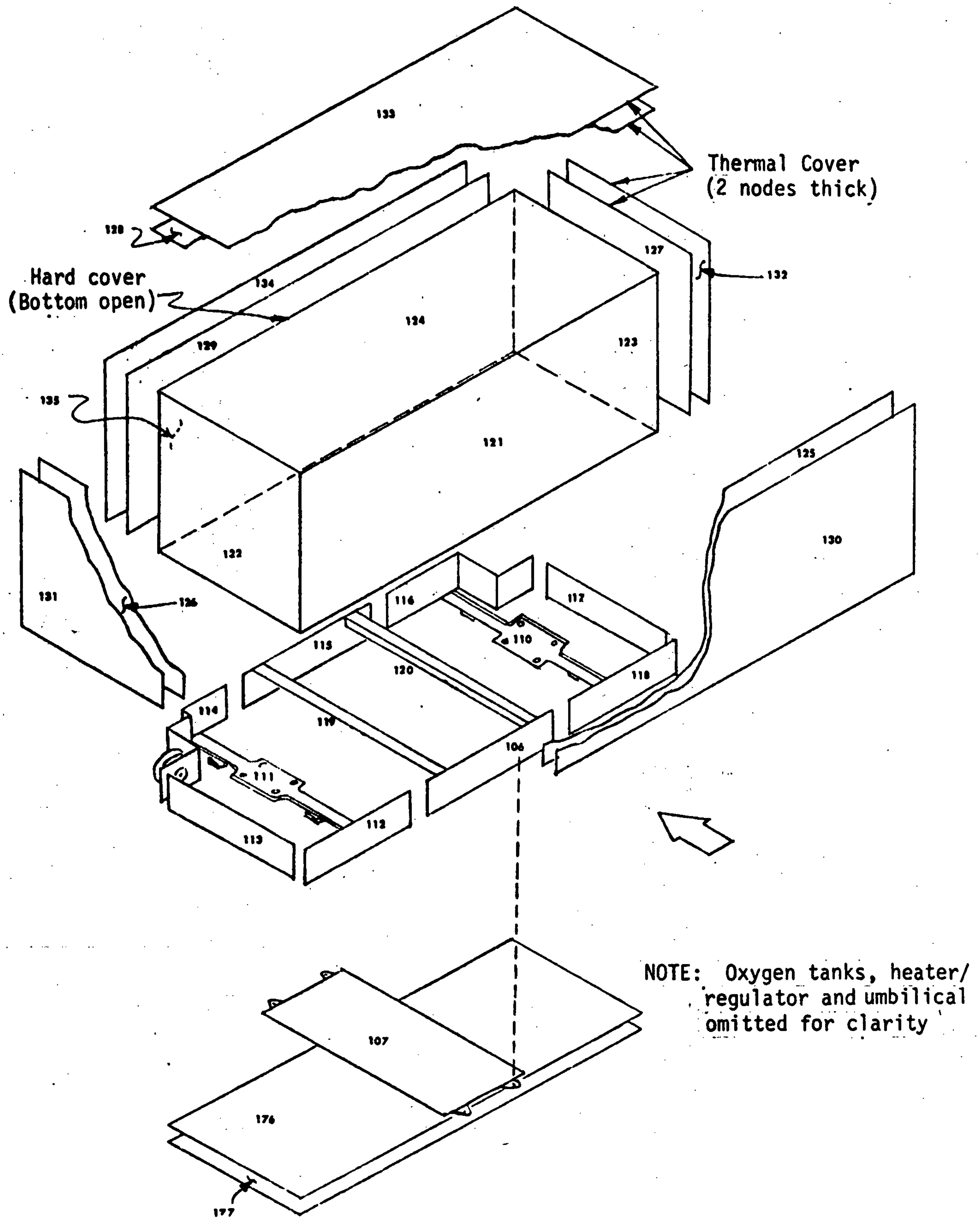


FIGURE 4-8 OPS HARDCOVER NODAL BREAKDOWN

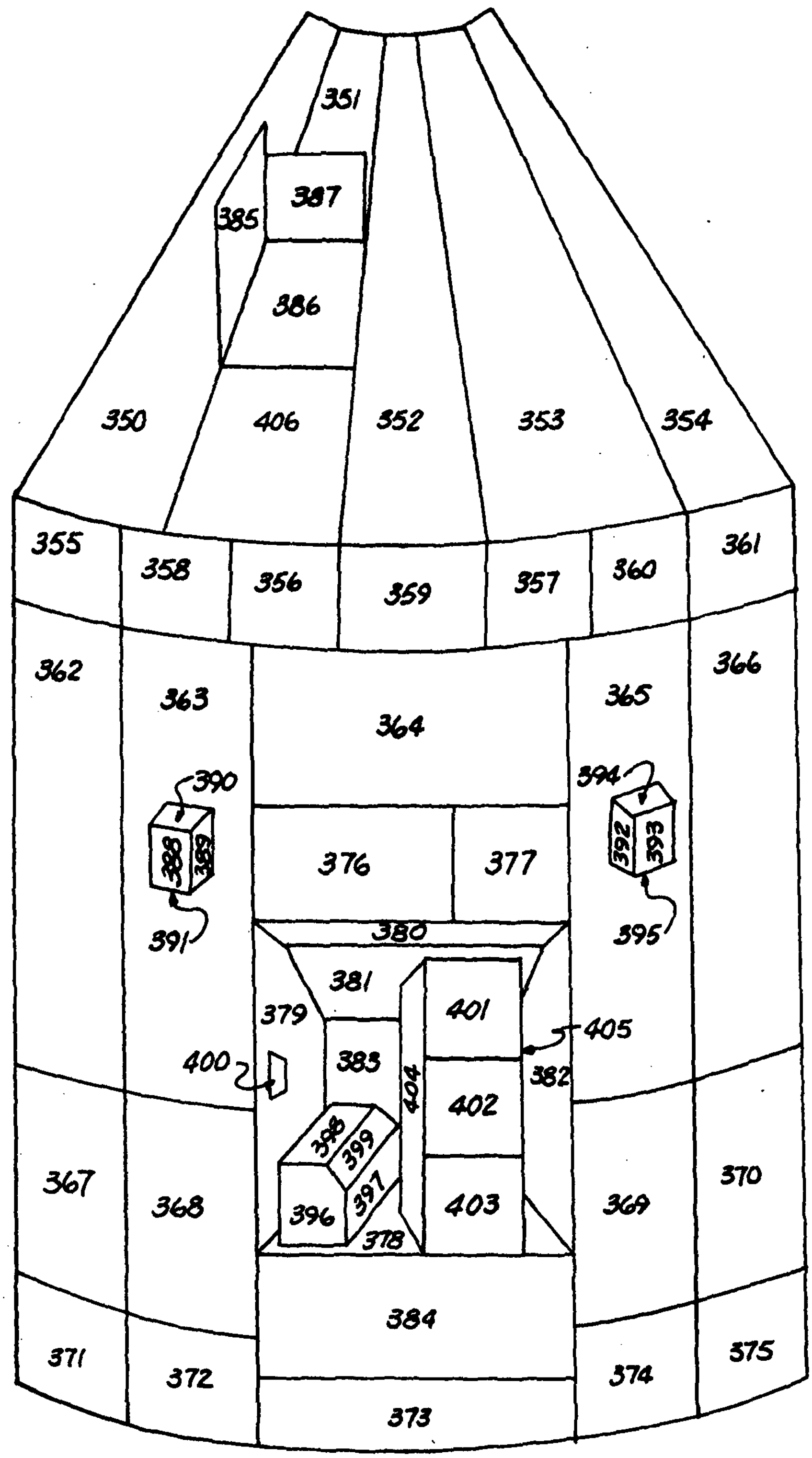


FIGURE 4-9 SIM BAY THERMAL MODEL

5.0 USER'S MANUAL

5.1 Program Description

This computer routine was written in Fortran V for the UNIVAC 1108 computer which has a core storage capacity of 65,536 words (with 53,248 words of memory available to the user) and a maximum of eight magnetic tape drives accessible. These tape units are used to maximum advantage for eliminating handling of large volumes of data cards and for providing the user with a flexibility to make data changes, interrupt the program for inspection of results and/or continuation of the analysis at a later time. There are options permitting the use of thirteen separate tape units, however, some of the options are mutually exclusive, so that no more than eight units are required at any given time.

A flow schematic of the routine is given in Figure 5-1. The program makes use of the overlay feature of Fortran V to provide for a large data block by minimizing the amount of core storage required for the program during data execution. This is accomplished by having subroutines SUB1, SUB2, SUB3, SUB4, SUB5, SUB6, and SUB7 share the same core storage location.

The first six main subroutines (SUB1 through SUB6) read, process and store data in a packed data block, and the seventh subroutine (SUB7) performs the analysis. The operations performed by each subroutine are outlined briefly in the following paragraphs.

MAIN calls the seven main subroutines (SUB1 through SUB7)

SUB1

1. Calls subroutine SUBX to read the first two data cards and stores all of the first for a heading to be printed at the top of every page of output; stores the parameters of the second card.

2. Tests the restart code. If it is zero, the data processing will be continued by SUB1 as described in the following paragraphs. If it is one or two, this indicates that all data is from the dump of a previous problem. In the case where the restart code is one, SUB1 reads data from Unit J. When the restart code is zero, execution is transferred through MAIN to SUB6.

3. Calls subroutine EDIT if required to make changes to the data tape.

FIGURE 5-1 EMU PROGRAM SCHEMATIC

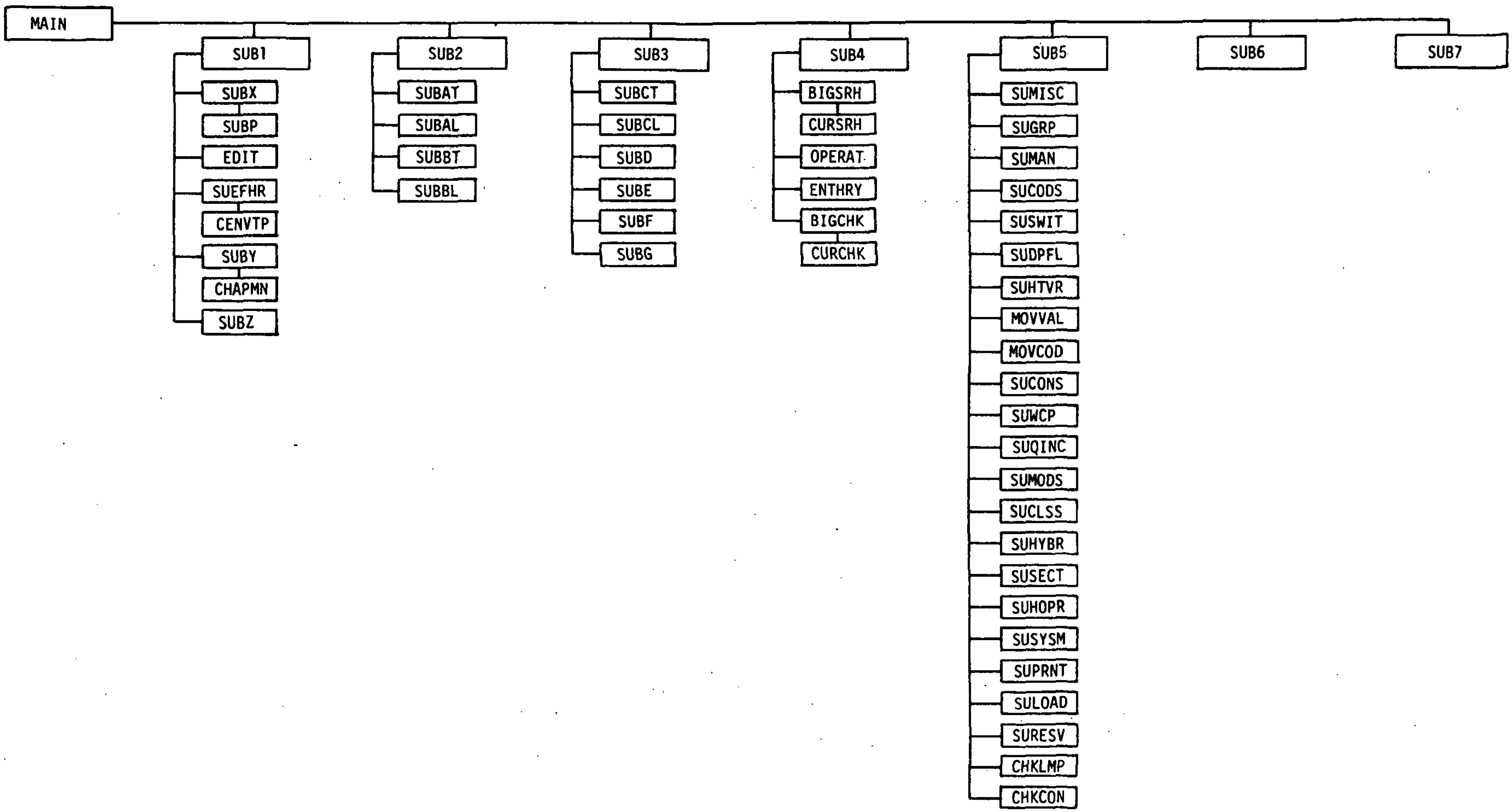
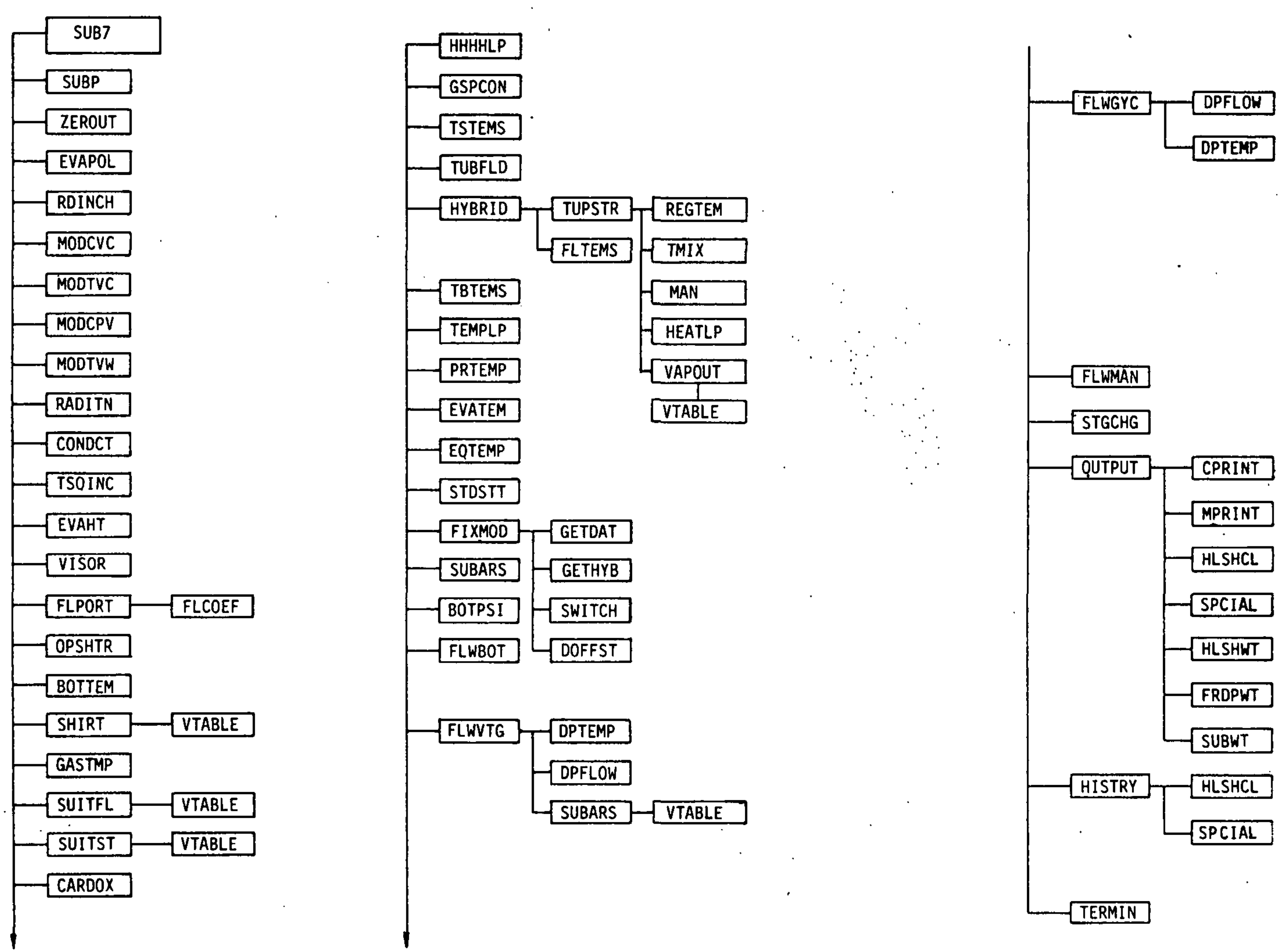


FIGURE 5-1 (CONT'D) EMU PROGRAM SCHEMATIC



4. Calls subroutine SUEHFR which reads and stores the parameters of the third data card, which calls subroutine CENVTP if required to create absorbed heat flux, prescribed temperature and radiant interchange mode curves on tape Unit E using data on tape Unit D and parameter cards 4 and 5.

5. Calls subroutine SUBY to read, check and store the parameters on cards 6 through 20, which calls subroutine CHAPMN to calculate the fraction of the incident solar absorbed by the visors.

6. Calls subroutine SUBZ to read and store the parameters on cards 21 through 26.

7. Writes amount of data space used by parameter card data.

8. Returns to MAIN which calls subroutine SUB2.

<u>SUB2</u>

1. Calls subroutine SUBAT to read, check and store the fluid type data.

2. Writes amount of data space used thus far.

3. Calls subroutine SUBAL to read, check and store the fluid lump data.

4. Writes amount of data space used thus far.

5. Calls subroutine SUBBT to read, check and store the tube type data.

6. Writes amount of data space used thus far.

7. Calls subroutine SUBBL to read, check and store the tube lump data.

8. Writes amount of data space used thus far.

9. Returns to MAIN which calls SUB3.

<u>SUB3</u>

1. Calls subroutine SUBCT to read, check and store the structure type data.

2. Writes amount of data space used thus far.

3. Calls subroutine SUBCL to read, check and store the structure lump data.

4. Writes amount of data space used thus far.

5. Calls subroutine SUBD to read, check and store local temperature perturbation data, heat leak data, and heat storage data.

6. Writes amount of data space used thus far.

7. Calls subroutine SUBE to read, check and store helmet and visor data, lump identification data, and configuration-associated node identification data.

8. Writes amount of data space used thus far.

9. Calls subroutine SUBF to read, check and store heat flux curve assignment data and prescribed wall temperature data.

10. Writes amount of data space used thus far.

11. Calls subroutine SUBG to read, check and store time variant mass data and time variant connection data.

12. Writes amount of data space used thus far.

13. Returns to MAIN which calls subroutine SUB4.

SUB4

1. Reads, checks and stores all the curve data.

2. Calls subroutine BIGSRH to setup curve type number information, BIGSRH calls subroutine CURSRH to see if a curve is needed.

3. Calls subroutine OPERAT to alter code curves by a $\pm$ .5 and converts temperature curves from degrees Fahrenheit to degrees Rankine.

4. Checks for specific heat curve and calls subroutine ENTHPY to generate an enthalphy curve and a reverse enthalpy curve.

5. Calls subroutine BIGCHK to setup calls to CURCHK for curve types. BIGCHK calls subroutine CURCHK to see if necessary curves have been supplied.

6. Writes amount of data space used thus far.

7. Returns to MAIN which calls SUB5.

SUB5

1. Calls subroutine SUMISC to define some constant values.

2. Calls subroutine SUGRP to setup arrays for the last fluid lump in each tube, for fluid lumps down a tube for each tube, and for tube lump numbers which enclose the fluid lumps down each tube.

3. Calls subroutine SUMAN to setup the 43 man nodes temperatures, checks and stores enclosed fluid lumps for the man's ten skin and undergarment tube lumps.

4. Calls subroutine SUCODS to set codes for special fluid, tube and structure lumps which are not to have temperature calculations.

5. Calls subroutine SUSWIT to set logical codes.

6. Calls subroutine SUDPFL to setup data for pressure drop analysis.

7. Calls subroutine SUHTVR to setup data for helmet and visor analysis.

8. Calls subroutine MOVVAL to interpolate specific heat, conductivity and time variant mass curves for initial conditions.

9. Writes amount of data space used thus far.

10. Calls subroutine MOVCOD to move code arrays to configuration data block.

11. Calls subroutine SUCONS to setup data for radiation and conduction connections between tubes and structure lumps.

12. Calls subroutine SUWCP to setup data for weight-specific heat of tube and structure lumps.

13. Calls subroutine SUQINC to setup data for lumps with incident heat curves.

14. Calls subroutine SUMODS to setup codes for classes of lumps to be analyzed for each EMU configuration mode.

15. Calls subroutine SUCLSS to store lumps by classes for EMU configuration modes. SUCLSS writes amount of data space used thus far.

16. Calls subroutine SUHYBR to setup codes for the order of hybrid calculations for each EMU configuration mode.

17. Calls subroutine SUSECT to store fluid lumps to be analyzed for each EMU configuration mode.

18. Writes amount of data space used thus far.

19. Calls subroutine SUHOPR to setup data space for various types of analysis for a particular EMU configuration mode.

20. Calls subroutine SUSYSM to setup initial constants and set diverter valve conditions.

21. Calls subroutine SUPRNT to setup temperature print array.

22. Calls subroutine SULOAD to zero arrays for initial conditions.

23. Calls subroutine SURESV to setup some arrays for use during iteration loop.

24. Calls subroutine CHKLMP to check lumps in certain tubes as defined under restrictions.

25. Calls subroutine CHKCON to check lumps which cannot have connections.

26. Writes amount of data space used thus far.

27. Returns to MAIN which calls SUB6.

SUB6

1. Stores initial temperatures for the forty-three nodes of the man.

2. Stores area for heat transfer and its reciprocal for the undergarment tube lumps.

3. Test the plot code. If it is not zero, the title and item count are written on the first record of tape Unit I.

4. Test and code for a restart from a previous plot tape. If it is not zero, temperatures are read from tape unit H for the time input as TMPTIM.

5. Returns to MAIN which calls SUB7.

SUB7

1. Test the restart code (ISTART). If it is zero, execution is transferred to FIXMOD; otherwise execution is continued as follows:

2. Test the SIM bay prescribed temperature code (NPRTCD). If it is not zero, then SIM bay prescribed temperature curves (Type 11) read from tape Unit L.

3. Test the heat flux and prescribed temperature code (NENVTP). If it is not zero, then absorbed heat curves are read from Unit E.

4. Calls subroutine ZEROUT to zero arrays for conductance summation, temperature change and heating rates for fluid, tube and structure lumps.

5. Calls the following subroutines as needed:

(a) EVAPOL which interpolates and stores values for absorbed heat flux (Type 19), prescribed temperature (Type 20) and the generated radiant interchange mode curves.

(b) RDINCH which reads radiation connections from UNIT G.

(c) MODCVC which calculates connection value for lumps with conductivity variant connections.

(d) MODTVC which calculates connection value for lumps with time variant connections.

(e) MODCPV which calculates weight-specific heat for lumps with variant specific heat.

(f) MODTVW which calculates weight-specific heat for lumps with time variant mass.

(g) RADITN which calculates and stores heat rate for lumps with radiation connections.

(h) CONDCT which calculates and stores heat rate for lumps with conduction connections.

(i) TSQINC which adds heat rate for lumps with incident heat curves (Type 9).

(j) EVAHT which adds heat rate for absorbed heat fluxes.

(k) VISOR which calculates the amount of heat absorbed by each helmet and visor lump.

6. Calls subroutine FLPORT which calls subroutine FLCOEF to calculate heat transfer coefficient for fluid lumps.

7. Calls the following subroutines as needed:

(a) OPSHTR which determines whether the oxygen purge system heater is on or off and adds the heat to appropriate lump if it is on.

(b) BOTTEM which calculates temperature for oxygen purge system and primary oxygen bottles.

(c) SHIRT which calculates variables needed when the man is in a shirtsleeve mode.

(d) GASTMP which calculates gas temperature for man fluid lumps.

(e) SUITFL which calculates variables for suit with flowing gas.

(f) SUITST which calculates variables for suit with stagnant gas.

(g) CARDOX which calculates the partial pressure of carbon dioxide in the helmet.

(h) HHHHLP which calculates the heat transfer coefficient and conductance summation for local temperature perturbation tube lumps.

(i) GSPCON which calculates the heat transfer coefficient, conductance and heat rate for special connection of a fluid lump to a tube lump.

(j) TSTEMS which calculates temperature for structure lumps being analyzed.

(k) TUBFLD which calculates conductance and heat rates for tube and fluid lumps being analyzed.

8. Calls subroutine HYBRID which determines fluid lump temperatures and lumps requiring special calculation using the following subroutines:

(a) TUPSTR which determines the upstream temperature for the lumps using the following subroutines:

(1) REGTEM which calculates the upstream temperature for the oxygen purge system and primary oxygen system regulators.

(2) TMIX which calculates a temperature when two or more fluids are mixed together.

(3) MAN which calculates the man temperatures.

(4) HEATLP which calculates heat rate for local perturbation tube lumps.

(5) VAPOUT which calculates water vapor added to the gas by the man, and specific humidity out of the suit.

(b) FLTEMS which calculates temperatures of fluid lump being analyzed.

9. Calls the following subroutines as needed:

(a) TBTEMS which calculates temperatures of tube lumps being analyzed.

(b) TEMPLP which calculates temperatures for local perturbation fluid and tube lumps.

(c) PRTEMP which interpolates prescribed wall temperature curves type 10 and sets temperatures of appropriate lumps.

(d) EVATEM which sets the temperature of lumps with prescribed temperature curves, type 20.

(e) EQTEMP which sets temperatures of unanalyzed helmet and visor lumps to temperature of analyzed lumps.

(f) STDSST which checks man's sweat or shiver rate for stabilization and temperature difference against steady state criterion.

10. FIXMOD which set variables for this iteration depending on the helmet and EMU configuration modes. It calls subroutines GETDAT and

GETHYB to store lumps to be analyzed in this iteration, DOFFST to doff the suit and SWITCH which determines logical variables which are used by SUB7 to determine which subroutines will be called.

11. Calls the following subroutines as needed:

(a) SUBARS which sets inlet temperature, flowrate and pressure into the suit when the ARS is activated.

(b) BOTPSI which determines pressure of the oxygen purge system and primary oxygen system bottles.

(c) FLWBOT which sets flowrate in oxygen purge system tubes 7 and 8 and primary oxygen system tubes 4 and 6.

(d) FLWVTG which sets flowrate in oxygen tubes. FLWVTG calls DPTEMP, DPFLOW and SUBARS which calculate pressure drop in the flow tubes.

(e) FLWGYC which sets flowrate in tube 4. FLWGYC calls DTEMP and DPFLOW which calculate pressure drop in the tubes mentioned above.

(f) FLWMAN which sets flowrate in the man oxygen tubes.

(g) STGCHG which calculates water vapor of suit gas nodes when the suit has no flow.

12. Calls the following when it is time to print:

(a) OUTPUT which writes headings.

(b) CPRINT which writes consumable data.

(c) MPRINT which writes man temperatures and man associated quantities.

(d) HLSHCL which calculates heat leak and heat storage.

(e) SPCIAL which calculates solar energy transmitted through the visors and added to the first heat leak group.

(f) HLSHWT which writes heat leak and heat storage data.

(g) FRDPWT which writes flowrates and pressure drops.

(h) SUBWT which converts a block of temperatures from Rankine to Fahrenheit, writes the temperatures, and converts them back to Rankine.

(i) HISTRY which writes history tape on Unit K.

(j) TERMIN which writes a message when the run is terminated.

13. Test the computer time usage and ends the run if requested time is exceeded.

14. Writes the entire data block and the variable block on tape Unit I, if the run is ended before completion or if the dump option is used, so that the problem can be restarted at a later time.

Miscellaneous

(1) Function BIPOL - does table look-up and straight line interpolation on bi-variant curves.

(2) Function Pol - does table look-up and straight line interpolation.

(3) Subroutine SPCTIM - checks data space required against data space available and writes amount of data used.

(4) Subroutine SUBP - starts a new page of output and writes parameter card one as a heading.

5.2 List of System Subroutines Used

The following is a list of the Univac 1108, Fortran V, system subroutines which are used with the EMU routine.

*1.	ALOG	12.	NEXP2$	23.	NRWND$
*2.	CBRT	13.	NFINP$	24.	NSTOP$
*3.	CLOCK	14.	NFMT$	25.	NTAB$
4.	DEPTH	15.	NFOUT$	*26.	NTRAN
*5.	EXP	16.	NFTV$	*27.	SQRT
6.	FPACK$	17.	NIER$	28.	THRU$
7.	MAUTO$	18.	NININ$	29.	TINTL$
8.	NBDCV$	19.	NINPT$	30.	TLABL$
9.	NBUFF$	20.	NIOIN$	31.	TSCRH$
10.	NCNVT$	21.	NOTIN$	32.	TSWAP$
11.	NERR$	22.	NOUT$		

* These subroutines are necessary regardless of the system on which the program is run.

5.3 MSC Run Submission Requirements

For operation on the MSC Univac systems (Fortran V), using the overlay provisions, the program is stored on tape and the data deck with

appropriate control cards submitted.

The EMU deck set up is as follows:

```
* 7
  8Z_RUN

* 7
  8N_MSG

  7
  8_ASG_A=AXXXXX (Input Program Tape Number)

  7
  8_ASG_B=AXXXXX (Input Old Data Tape Number) or

  7
  8S_ASG_B=DATA (Output New Data Tape)

  7
  8_ASG_C=AXXXXX (Input Old Data Tape Number)

  7
  8_ASG_D=AXXXXX (Input EHFR Output Tape Number)

  7
  8_ASG_E=AXXXXX (Input Heat Flux & Prescribed Temperature Tape Number ) or

  7
  8S_ASG_E=FLUX (Output Heat Flux and Prescribed Temperature Tape)

  7
  8_ASG_G=AXXXXX (Input Radiant Interchange Data Tape Number)

  7
  8_ASG_H=AXXXXX (Input NEWTMP Tape Number)

  7
  8S_ASG_I=DUMP (Output Data Dump and/or Plot Tape)

  7
  8_ASG_J=AXXXXX (Input Restart Tape Number)

  7
  8_ASG_L=AXXXXX (Input SIM Bay Prescribed Temperature Tape Number)

  7
  8_XQT_CUR

  __TRW_A
```

_ _IN_A
_ _TRI_A
7
8_XQT_PROG
DATA (See Section 5.7)
7
8_EOF
* See CAD Procedures Manual - MSC EXEC II Part 19 Page 19.30.110

Description of Tape Units Used:

A - is the tape on which the program is stored and is always an input tape. (A is logical unit 1)

B - may be an input tape, an output tape, or not used at all; depending on the value of INDATA. If INDATA = 0, B is not used at all. If INDATA = 1 or 2, B is an output tape on which the new data is stored. If INDATA = 3, B is an input tape on which data has been stored prior to this run. (B is logical unit 2)

C - is an input tape necessary only if INDATA = 2. The data to be edited was stored on this tape in an earlier run. (C is logical unit 3)

D - is an input tape necessary only if NENVTP = 2. This tape is an EHFR output tape. (D is logical unit 4)

E - may be an input tape, an output tape or not used at all, depending on the value of NENVTP. If NENVTP = 0, E is not used at all. If NENVTP = 1, E is an input tape which was created on an earlier run. If NENVTP = 2, E is an output tape on which created heat flux and prescribed temperature curves are written (E is logical unit 7)

G - is an input tape necessary only if NRIC = 1. This tape has script FA connections for radiant interchange and radiation to space of external suit nodes. (G is logical unit 9)

H - is an input tape necessary only if NEWTMP = 1. This tape was the I tape from a previous problem with IPLOTN = 1. (H is logical unit 10)

I - is an output tape necessary only if IDUMP = 1 and/or IPLOTN = 1. This tape need not be generated unless the problem is to be restarted and/or plots of the mission are to be made. (I is logical unit 11)

J - is an input tape necessary only if ISTART = 1 or 2. This tape was the I tape from a previous run with IDUMP = 1. (J is logical unit 12)

L - is an input tape necessary only if NPRTCD = 1. This tape is used to supply SIM bay prescribed temperature curves. Every type 11 (Section 5.7 Curve Data Cards) curve must start on the data tape. (L is logical unit 14)

If a tape is an input tape, the number of the tape should be punched immediately following the equal sign without skipping any spaces between the equal sign and the tape number. If a tape is an output tape, the same rule applies except the number is replaced by a symbolic name. This symbolic name should also appear on the run request card under the heading "FILE NAME" for the corresponding output tape.

All input and output tapes must be so designated on the run request card (MSC FORM 588). If the output tapes are to be saved, separate tape reel labels (MSC FORM 874) should be submitted with the run for each tape. The appropriate information for each tape should be supplied on these forms. A method for estimating run time and program output required on these forms is provided in the following section.

5.4 Run Time and Output Estimation

Run time for the EMU may be estimated for the Univac 1108 using the following equation:

$$RTIME = AI + \left(\frac{FL + TL + SL}{40800}\right)\left(\frac{TAU - TIME}{TINCMN}\right)$$

where:

RTIME	=	requested computer time in minutes
FL	=	number of fluid lumps
TL	=	number of tube lumps
SL	=	number of structure lumps
TAU	=	mission completion time, hours
TIME	=	mission start time, hours
TINCMN	=	input time interval, hours
AI	=	0, if the run is a restart
	=	3, if the run is not a restart

This expression is not valid when the print interval is less than 0.1 hours. This expression is also an approximation because the amount of time spent in determining flow rates is dependent on the severity of the transient being run and cannot be readily estimated in advance.

Output from EMU may be estimated using the following equation:

$$NPO = 18 + 3 \frac{TAU - TIME}{DELTAU} + 23\ AI + 70\ BI$$

where:

NPO	=	number of pages of output
TAU	=	mission completion time
TIME	=	mission start time
DELTAU	=	print interval
AI	=	0, if the run is restart
	=	1, if the run is not a restart
BI	=	0, if the data tape is not edited
	=	1, if the data tape is edited

5.5 Restrictions

Programming, analytical, and core storage space restrictions applicable to the EMU are outlined in the following paragraphs.

5.5.1 Programming

Some of the programming restrictions are described in other parts of the report and are listed here to emphasize their importance.

A. A fluid lump may be enclosed by more than one tube lump, but it must be enclosed by at least one.

B. When setting up the fluid lump data, care must be exercised to insure that upstream lumps are set up properly. Data should be listed so that it is possible to go from the last lump in the tube to the first lump in that tube simply by following the upstream lump numbers. All fluid lumps in the tube should be covered in this search.

C. When conduction data is set-up, the second conductance value may be zero, but the first should never be in order to save core storage space.

D. Tubes 12, 13, 17, 11, 14, 18, 15, 19, 16 and 20 contain the vent gas flow over the trunk, right arm, right leg, head,

right hand, right foot, left arm, left leg, left hand and left foot respectively and must contain one and only one fluid lump. Each preceding fluid lump must be enclosed by at least two tube lumps one of which must be the corresponding skin tube lump number. Additional tube lumps, enclosing the suit fluid lumps and representing the inside suit wall, are required by the program.

E. Tube 9 must contain at least two fluid lumps.

F. The structure lump of oxygen in the OPS bottle on left side and right side and the tube lump surrounding the first lump in tube 9 must not have any connections.

G. If a lump has a prescribed temperature, the temperature is prescribed for the entire problem according to the curve data input.

5.5.2 Analytical

In addition to the analytical restrictions for any finite difference approximation to differential equations, the user of the EMU should also be aware of the following:

A. The EMU has special equations or curves for computing the pressure drop of various components. In order to compute a pressure drop of zero for the fluid lump which represents the component, a wetted perimeter of zero must be specified for the fluid lump. However, the specifying of a wetted perimeter of zero causes the calculation of a zero heat transfer coefficient for the fluid lump. Therefore, if a heat transfer coefficient other than zero is needed, it must be specified on a curve as a function of flow rate.

B. The EMU automatically determines for the lumps on the visors, the amount of incident solar and incident infrared radiation absorbed as a function of visor position. The visor node connections are made and broken automatically according to visor position. The pressure bubble lumps connected to the LEVA shell lumps must be done manually by use of lumps with time variant properties. The time variant curve must be consistent with the helmet mode curve which is a function of mission time.

5.5.3 Core Storage Space

The computer program requires approximately 8000 core locations. In addition, a blank common block of 40,980 is allocated for storing input and calculated data. The largest part of the common block is assigned to an array called DATA. Basically the size of this array is determined by the size of core and the size of the SUB7 link. For operation on the Univac 1108 the dimensioned size of DATA is 40,000 locations. The DATA array is divided into three sections: transient, permanent and temporary. The transient section has two blocks, iteration and configuration, which share the 14,000 locations available. Only one block is stored in core at a time, while the other is stored on a drum. The iteration block occupies core all the time except when an EMU configuration change takes place and the configuration block is in core to make necessary changes to the permanent section. The permanent and temporary sections have variable length which cannot exceed 26,000 locations. These storage values are allocated as shown in the following paragraph.

5.6 <u>Program Options</u>

5.6.1 Plot Tape

A "1" punch in column 68 of parameter card 2 will cause the generation of a plot tape. This tape will have all of the fluid, tube, and structure lump temperatures, plus other items indicated below, recorded on it under control of the plot interval given on Card 2. The plot tape is generated on tape UNIT I. Setup cards are required when the program is submitted to cause the tape to be mounted as discussed in Section 5.3. Also, the computer request card must indicate that there is to be an output tape on UNIT I.

The format of the plot tape is:

<u>Record No. 1</u>

Title (from title card, 12A6), 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 2, 2, 2, 1, 1, 1, 7, 8, 43, number of groups of heat leak calculations, number of groups of heat storage calculations, number of flowrates, number of pressure drops, number of fluid temperatures, number of tube temperatures, number of structure temperatures.

Record No. 2

Time, crewman stored heat, partial pressure of CO_2 in helmet, dewpoint temperature in helmet, suit inlet specific humidity, suit outlet specific humidity, pressure in OPS bottles, X, X, X, X, crewman sensible heat loss, crewman evaporation heat loss, crewman latent heat loss, crewman storage rate, crewman shiver rate, crewman metabolic rate, oxygen in OPS bottles, X, X, X, X, X, X, unremoved sweat on crewman, crewman temperatures, flowrates, pressure drops, fluid lump temperatures, tube lump temperatures, and structure lump temperatures.

Record No. 3

Time, etc.

The last record has a negative time to indicate end of output. This record need not be included in the plot since the values printed out are identical to those on the previous record.

5.6.2 Restart

Requested Dump for Restarting

Any problem can be dumped and restarted at a later time. This is achieved by punching a "1" in column 70 on parameter card 2. This option is useful in data checkout in that a problem can be submitted for a short transient time, and, after examination of the results, restarted for a longer transient time. The computer request card must specify that the output tape is expected, and the proper set-up card must be included in the deck.

Automatic Dump for Restarting

If a problem does not attain the specified mission transient time within the requested computer time, the problem is dumped and may be restarted later. This occurs whether there is a "1" in column 70 on parameter card 2 or not. The computer request card must specify that an output tape is expected or the dump will be lost; a save tape label must also be provided.

Restart Procedure

The procedure for restarting a problem which has been dumped is:

(1) Fill out the computer request card as in an initial run, except specify the previously dumped tape as an input tape on Unit J.

(2) If on the initial run, an EHFR tape was input on Unit D, the output tape created on Unit E is specified as an input tape on restart. An EHFR tape cannot be used directly on restart.

(3) Submit only the first two of the data cards (that is, parameter cards 1 and 2) with a "1" punch in column 60 on Card 2 to indicate that data is to be read from a restart tape.

5.6.3 EDIT

The large number of data cards required for problems run on this routine presents three problems: (1) increased probability of operator and/or card reader error, (2) increased probability of a card reader jam, and (3) significant extra time required to read in data from the card reader when problem (2) occurs. For these reasons a routine was developed (Reference 14) for reader input data from tape with the capability for modifying the data on read-in.

The EDIT routine is called by parameter INDATA input on columns 61 and 62 on parameter card 2. Possible inputs are:

(1) INDATA = 0, All data is supplied on cards.

(2) INDATA = 1, All data is supplied on cards and the card images are written on tape on Unit B. (Should be specified as an output tape on job card).

(3) INDATA = 2, Use data input on tape on Unit C with desired changes on cards to write a new data tape on Unit B. (C is input tape and B is output tape)

(4) INDATA = 3, Use the data read in from Unit B without change. Parameter cards 1 and 2 are read in from cards. (B is input tape)

If INDATA = <0, the card images are punched as they are written on Unit B.

When INDATA = 2, deck set-up consists of parameter cards 1 and 2, the EDIT control cards (described below), and the new data cards (with the same format as the cards being replaced).

The EDIT control cards, used only when INDATA has a value of ± 2 are:

COLUMN	FORMAT	NAME	DESCRIPTION
1	A1	ID	* in column 1 identifies the card as an EDIT control card
6-15	I10	K3	Card number of first card to be removed if K3 is positive and K4 > 0. If K3 is negative, K3 is the card number of the card for which a merge correction will be performed. If K4 is blank or zero, cards change cards between this card and the next EDIT Control card will be added immediately following card K3.
16-25	I10	K4	Card number of last card to be removed prior to inserting the change cards in the data. If K3 is negative, K4 is ignored.

The Unit C tape is not altered in any way should there be errors in the edit deck which cause fatal errors in the LTV program. It is the responsibility of the user to maintain extra copies of the data tape and/or an up-to-date card deck.

5.6.4 Imposed Node Temperature History

It is possible to impose a temperature history on structure nodes for the duration of the problem. The temperature history is called a prescribed wall temperature and data preparation is given in Section 5.7.12.

5.6.5 Heat Flux and Prescribed Temperature Data From EHFR

The Environmental Heat Flux Routine (EHFR) outputs on a tape, incident heat in two wavelength bands (solar and infrared) for each helmet and visor node of its geometrical model of the EMU. Absorbed heat for each remaining node and a contact temperature is also output on the tape. This tape is used as input to the EMU simulator on tape Unit D when NENVTP = 2, the EMU simulator reads data from Unit D and creates on Unit E curves of absorbed heat, incident solar heat, incident infrared heat, and contact

temperature as specified on parameter cards 4 and 5. The incident solar and incident infrared heat curves are assigned in the Helmet and Visor Data (Section 5.7.8) while the absorbed heat and contact temperature curves are assigned in the Curve Assignment Data (Section 5.7.11). The tape created on Unit E on one run can be used on other runs as an input tape by specifying NENVTP = 1. The user can, by specifying NENVTP = 0, input curves requested on parameter card 3 in the Curve Data (Section 5.7.15) as type 19 and type 20 curves. Parameter cards 4 and 5 must be omitted and tapes are not specified for Unit D and Unit E. If NENVTP = 0, and NRIC = 1, the user must supply a type 21 (radiant interchange mode) curve. This curve determines the set of radiant interchange connection values to be used from Unit G as a function of time. The connection values should correspond to the variation in EHFR heat flux which is a function of the EMU geometric configuration.

To restart a run which uses an EHFR tape as input on Unit D, a tape must have been created on Unit E and saved for restart. The tape generated on Unit E becomes an input tape read from the same unit. Unit D cannot be used on restart. (Section 5.6.2)

5.7 DATA CARD PREPARATION FOR EMU

5.7.1 PARAMETER CARDS

Columns	Format	Title	Description
Card 1			
1-72	12A6	TITLE	Any 72 alphanumeric characters to be used for page heading
Card 2			
1-10	F10.5	TIME	Mission start time (hrs)
11-15	F5.5	TINCMN	Minimum time increment (hrs)
16-20	F5.5	PLTINC	Plot interval (hrs)
21-25	F5.5	DELTAU	Print interval (hrs)
26-35	F10.5	TAU	Mission completion time (hrs)
36-40	F5.0	SSTEST	Steady state tolerance (°F)
41-45	F5.0	RTIME	Computer time requested (minutes)
46-50	F5.0	TMPTIM	Time of initial temperatures from history tape (UNIT H)
51-55	F5.0	DPTOL	Pressure drop tolerance (.01)
56			Blank
57-58	I2	NSTEAD	= 0, Not steady state ≠ 0, Steady state run
59-60	I2	ISTART	= 0, New data follows = 1, Read data from restart tape to continue mission
61-62	I2	INDATA	= 0, All data supplied on cards = 1, Write card images on UNIT B = 2, Use cards from C to update B = 3, Use B without edit =-2, Punch data
63-64	I2	NEWTMP	= 0, Use current temperature tables = 1, Read initial temperatures from Unit H

Columns	Format	Title	Description
Card 2 (Continued)			
65-66	I2	NPRTCD	= 0, Use current SIMBAY prescribed temperature tables = 1, SIMBAY prescribed temperature tables supplied by UNIT L
67-68	I2	IPLOTN	= 0, No temperature history = 1, Write temperature history on UNIT I
69-70	I2	IDUMP	= 0, No dump tape to be written = 1, Dump data on UNIT I when either TAU or RTIME is exceeded
Card 3			
1-5	I5	NTFL	Total number of fluid lumps
6-10	I5	NTML	Total number of tube lumps
11-15	I5	NSL	Total number of structure lumps
16-20	I5	NIHEVA	Number of heat flux curves to be created from EHFR output or supplied in curve data. If none, enter zero.
21-25	I5	NPTEVA	Number of prescribed temperatures history curves to be created from EHFR output or supplied in curve data. If none, enter zero.
26-30	I5	NENVTP	Code for heat flux curves, type 19, and prescribed temperature curves, type 20, = 0, Curves supplied in curve data = 1, Heat flux and prescribed temperature curves read from UNIT E, = 2, Heat flux and prescribed temperature curves created on UNIT E from EHFR output on UNIT D
31-35	I5	NRIC	= 0, No radiant interchange tape = 1, Read radiant interchange tape on UNIT G.
Card 4			
1-5	I5	NUM	Curve number assigned to this group of combined heat fluxes (or temperature histories)
6-10	I5	NF	Number of heat fluxes (or temperature histories) from EHFR composing this group

Columns	Format	Title	Description
Card 5			
1-5	I5	NF1	First facet number corresponding to the heat flux (or temperature history) included in this group
6-10	F5.0	FRAC1	Fraction of heat flux (or temperature history) of first facet included in this group
11-15	I5	NF2	Second facet number corresponding to the heat flux (or temperature history) included in this group
16-20	F5.0	FRAC2	Fraction of heat flux (or temperature history) of second facet included in this group
21-25	I5	NF3	Third facet number corresponding to the heat flux (or temperature history) included in this group
26-30	F5.0	FRAC3	etc.

Alternate the facet number and fraction in the proper format through column 70. Then, repeat Card 5 until NF facet numbers and the appropriate fraction have been supplied. Repeat Card 4 followed by Card 5 for the heat flux curves NIHEVA times followed by Cards 4 and 5 for prescribed temperature history curves as required.

Columns	Format	Title	Description
Card 6			
1-10	E10.5	C1	Suit $\Delta P(psi) = C1 * \frac{T_{in}}{P_{in}} (\dot{W}_o)^{END1}$
11-20	E10.5	END1	
21-25	I5	LMPHTR	OPS heater tube lump number
26-30	I5	LSNHTR	OPS heater fluid sensor lump number
31-40	F10.5	TSEN1	OPS "heater-on" temperature, °F
41-50	F10.5	TSEN2	OPS "heater-off" temperature, °F
51-60	F10.5	QHTR	Heater dissipation rate, Btu/hr
Card 7			
1-5	I5	LIØPS1	Lump number of oxygen in OPS bottle on left side (structure)

Columns	Format	Title	Description
Card 7 (Continued)			
6-10	I5	LØØPS1	Lump number of shell of OPS bottle on left side (structure)
11-20	F10.5	HAØPS1	HA for left hand side OPS bottle, Btu/hr-°F
21-30	F10.5	PGØPS1	Initial pressure in left hand side OPS bottle, psi

Card 8

Same as Card 7 except for right hand side OPS bottle.

Card 9

Columns	Format	Title	Description
1-10	F10.5	VØLØPS	OPS bottle volume, in^3
11-20	F10.5	VØLPRI	Primary oxygen bottle volume, in^3
21-30	F10.5	CØ2WGT	Initial weight of $CØ_2$ in helmet, lb
31-40	F10.5	SYFRIN	Initial oxygen system flowrate, lb/hr
41-50	F10.5	AØRFIC	Area of orifice, in^2

Card 10

Columns	Format	Title	Description
1-5	I5	L1	Trunk skin tube lump number
6-10	I5	L2	Right arm skin tube lump number
11-15	I5	L3	Left arm skin tube lump number
16-20	I5	L4	Right leg skin tube lump number
21-25	I5	L5	Left leg skin tube lump number
26-30	I5	L6	Head skin tube lump number
31-35	I5	L7	Right hand skin tube lump number
36-40	I5	L8	Left hand skin tube lump number
41-45	I5	L9	Right foot skin tube lump number
46-50	I5	L10	Left foot skin tube lump number

Columns	Format	Title	Description
Card 11			
1-5	I5	L11	Trunk undergarment tube lump number
6-10	I5	L12	Right arm undergarment tube lump number
11-15	I5	L13	Left arm undergarment tube lump number
16-20	I5	L14	Right leg undergarment tube lump number
21-25	I5	L15	Left leg undergarment tube lump number
26-30	I5	L16	Head undergarment tube lump number
31-35	I5	L17	Right hand undergarment tube lump number
36-40	I5	L18	Left hand undergarment tube lump number
41-45	I5	L19	Right foot undergarment tube lump number
46-50	I5	L20	Left foot undergarment tube lump number
Card 12			
1-10	F10.5	RF1	Solar reflectivity of astronaut's face
11-20	F10.5	RF2	Solar reflectivity of inside of pressure bubble
21-30	F10.5	RF3	Solar reflectivity of outside of pressure bubble
31-40	F10.5	RF4	Solar reflectivity of inside of impact visor
41-50	F10.5	RF5	Solar reflectivity of outside of impact visor
51-60	F10.5	RF6	Solar reflectivity of inside of sun visor
61-70	F10.5	RF7	Solar reflectivity of outside of sun visor
Card 13			
1-10	F10.5	RFT	Solar reflectivity of helmet top
11-20	F10.5	T23	Solar transmissivity of pressure bubble
21-30	F10.5	T45	Solar transmissivity of impact visor
31-40	F10.5	T67	Solar transmissivity of sun visor

Columns	Format	Title	Description
Card 14			
1-10	F10.5	EM1	Infrared emittance of outer surface of sun visor
11-20	F10.5	EM2	Infrared emittance of outer surface of impact visor
21-30	F10.5	EM3	Infrared emittance of outer surface of helmet top
31-40	F10.5	EM4	Infrared emittance of outer surface of pressure bubble
41-50	F10.5	EM5	Infrared emittance of man's face
Card 15			
1-5	I5	NOXDEN	Oxygen density curve number
6-10	I5	NOXCON	Oxygen conductivity curve number
11-15	I5	NOXSPH	Oxygen specific heat curve number
16-20	I5	NOXVIS	Oxygen viscosity curve number
21-25	I5	NOXFFR	Oxygen friction factor curve number
Card 16			
1-5	I5	NWRDEN	Glycol water density curve number
6-10	I5	NWRCON	Glycol water conductivity curve number
11-15	I5	NWRSPH	Glycol water specific heat curve number
16-20	I5	NWRVIS	Glycol water viscosity curve number
21-25	I5	NWRFFR	Glycol water friction factor curve number
Card 17			
1-5	I5	NTCAB	Cabin gas temperature curve number
6-10	I5	NTDEWC	Cabin gas dew point temperature curve number
11-15	I5	NOXYDP	Suit inlet dew point temperature curve number

Columns	Format	Title	Description
Card 17 (Continued)			
16-20	I5	NOXYIT	Suit inlet temperature curve number
21-25	I5	NØ2T1	Tank 1 oxygen inlet temperature curve number
26-30	I5	NØ2T2	Tank 2 oxygen inlet temperature curve number
31-35	I5	NØ2T3	Tank 3 oxygen inlet temperature curve number
36-40	I5	NGYCTP	Glycol water inlet temperature curve number

All curves on this card are type 12.

Card 18

Columns	Format	Title	Description
1-5	I5	NZFACT	Compressibility factor curve number, Z (PR,TR)
6-10	I5	NEBLOW	Oxygen enthalpy curve number, H (P,T)

All curves on this card are type 33.

Card 19

Columns	Format	Title	Description
1-5	I5	NSLEAK	Suit leakage rate curve number
6-10	I5	NXM	Metabolic rate curve number
11-15	I5	NUEFF	Man efficiency curve number
16-20	I5	NPSUIT	Suit gas pressure curve number
21-25	I5	NGRAV	Gravity multiplying factor curve number
26-30	I5	NVCAB	Cabin freestream velocity curve number
31-35	I5	NVEFF	Cabin ventilation efficiency curve number
36-40	I5	NPCAB	Cabin gas pressure curve number
41-45	I5	NOXYFL	Suit inlet gas flow curve number
46-50	I5	NØ2P1	Tank 1 oxygen pressure curve number

Columns	Format	Title	Description
Card 19 (Continued)			
51-55	I5	NØ2P2	Tank 2 oxygen pressure curve number
56-60	I5	NØ2P3	Tank 3 oxygen pressure curve number
61-65	I5	NGYCFR	Glycol water flowrate curve number
66-70	I5	NEVRØP	EVA panel regulator outlet curve number

All curves on this card are type 34.

Card 20

1-5	I5	NOPS	OPS flowrate curve number
6-10	I5	NHMOD	Helmet mode curve number
11-15	I5	NEMODE	EMU configuration mode curve number

All curves on this card are type 35.

5.7.2 FLUID DATA CARDS

Card 21

1-5	I5	NFLT	Number of types of fluid lumps

Card 22 (Fluid Type Cards)

1-25			Blank
26-30	I5	NKPDC	Head loss coefficient curve number
31-35	I5	NHHH	= 0, Use regular equation for HHH ≠ 0, Curve number for HHH = f ($\dot{w}$)
36-45	F10.5	FLL	Fluid lump length, inches
46-55	F10.5	CSA	Fluid cross sectional area, sq. in.

Columns	Format	Title	Description
Card 22 (Continued)			
56-62	F7.5	WP	Wetted perimeter, inches
63-67	F5.4	FRE	Factor for computing friction factor as a function of Reynold's number. Routine sets to 1.0 if left blank
68-72	I5	LTYPE	Type number

Repeat Card 22 for each fluid type.

Card 23 (Fluid Lump Cards)

1-5	I5	LN	Lump number
6-10	I5	NLU	Lump upstream. NLU = 0 for first lump in every tube
11-15	I5	NTB	Tube number
16-20	I5	NTYPEF	Type number
21-30	F10.5	FTI	Initial temperature, ^{o}F

Repeat Card 23 for every fluid lump.

5.7.3 TUBE DATA CARDS

Card 24

1-5	I5	NMLT	Number of types of tube lumps

Card 25 (Tube Type Cards)

1-5	F5.0	WGTT	Weight of tube lump, lbs
6-10	I5	NCØNCT	Conductivity curve number
11-15	I5	NSHCT	Specific heat curve number
16-20	I5	NTCT	Number of tube lumps 'conducted to' by tube lumps of this type
21-25	I5	NFCTT	Number of structure lumps 'conducted to' by tube lumps of this type
26-30	I5	NTRT	Number of tube lumps 'radiated to' by tube lumps of this type

Columns	Format	Title	Description
Card 25 (Continued)			
31-35	I5	NFRTT	Number of structure lumps 'radiated to' by tube lumps of this type
36-45	F10.5	AHT	Area of heat transfer to enclosed fluid lump, sq. in.
46-55	F10.5	AERT	Area of surface for incident heat application, sq. in.
56-65	F10.5	FAC	Factor for dividing conduction distances. Routine sets to 1.0 if left blank
66-70	I5	LTYPE	Type number
Card 26	(Conduction Data, required for all lumps conducted to by tube lumps of this type)		
1-5	F5.0	$R1_1$	Conduction data for tube lumps of this type of the first lump listed in the connections on the tube lump card
6-10	F5.0	$R2_1$	$U = \dfrac{1}{\dfrac{R1_1}{K_1} + \dfrac{R2_1}{K_2}}$ Resistor values are input in pairs, but R_2 may be left blank when thermal conductivity is constant.
11-15	F5.0	$R1_2$	Conduction data for tube lumps of this type to the second lump listed in the connections on the tube lump cards
16-20	F5.0	$R2_2$	
.	.	.	.
.	.	.	.
.	.	.	.
61-65	F5.0	$R1_7$	Conduction data for tube lumps of this type to the seventh lump listed in the connections on the tube lump card
66-70	F5.0	$R2_7$	

Repeat Card 26 as many times as needed to supply conduction data for the total number of lumps conducted to by tube lumps of this type. Data must be given as follows: (1) all conduction data to tube lumps, (2) all conduction data to structure lumps.

Columns	Format	Title	Description
Card 27	(Radiation Data, required for all lumps radiated to by tube lumps of this type)		
1-5	F5.0	FA1	Gray-body shape factor, FA (sq. in.) between tube lumps of this type and the first lump 'radiated to' listed in the connections on the tube lump cards
6-10	F5.0	FA2	Gray-body shape factor between tube lumps of this type and the second lump 'radiated to' listed in the connections on the tube lump card
.	.	.	.
.	.	.	.
.	.	.	.
66-70	F5.0	FA14	Gray-body shape factor between tube lumps of this type and the 14th lump 'radiated to' listed in the connections on the tube lump cards

Repeat Card 27 as many times as needed to supply the gray-body shape factor for the total number of lumps radiated to by tube lumps of this type. Data must be given as follows: (1) all radiation data to tube lumps, (2) all radiation data to structure lumps.

Repeat Card 25 (followed by Cards 26 and 27 if needed) for each tube type.

Card 28	(Tube Lump Cards)		
1-5	I5	LN	Lump number
6-10	I5	NFL	Enclosed fluid lump number
11-15	I5	NTYPET	Type number
16-25	F10.5	TTI	Initial temperature, °F
26-30	I5	NQICT	Incident heat curve number
31-35	I5	NTL1	First lump to which this tube lump has a connection either by conduction or radiation
.	.	.	.
.	.	.	.
.	.	.	.
66-70	I5	NTL8	Eighth lump to which this tube lump has a connection

Columns	Format	Title	Description
Card 29	(Additional connections, if required)		
1-5	I5	NTL9	Ninth lump to which this tube lump has a connection
.	.	.	.
.	.	.	.
.	.	.	.
66-70	I5	NTL22	Twenty-second lump to which this tube lump has a connection

The order of the connected lumps is the same as the other in which the conduction and radiation data were given on the corresponding type card.

Recall that the connections should be listed as follows; conduction to tube lumps, conduction to structure lumps, radiation to tube lumps and radiation to structure lumps. Repeat Card 29 if needed to supply all lumps to which the tube lump has a connection.

Repeat Card 28 (followed by Card 29, if required) for every tube lump.

5.7.4 STRUCTURE DATA CARDS

Card 30

1-5	I5	NT	Number of types of structure lumps

Card 31 (Structure Type Cards)

1-5	F5.0	WGTS	Weight of structure lump, lbs
6-10	I5	NCØNCS	Conductivity curve number
11-15	I5	NSHCS	Specific heat curve number
16-20	I5	NFCTS	Number of structure lumps 'conducted to' by structure lumps of this type
21-25	I5	NFRTS	Number of structure lumps 'radiated to' by structure lumps of this type
26-35	F10.5	AERS	Area of surface for incident heat application, sq. in.
36-45	F10.5	FAC	Factor for dividing conduction distances. Routine sets to 1.0 is left blank
66-70	I5	LTYPE	Type number

Columns	Format	Title	Description

Card 32 (Conduction Data, required for all lumps conducted to by structure lumps of this type)

1-5	F5.0	$R1_1$	Conduction data for structure lumps of this type to the first lump listed in the connections on the structure lump card
6-10	F5.0	$R2_1$	
.	.	.	.
.	.	.	.
.	.	.	.
61-65	F5.0	$R1_7$	
66-70	F5.0	$R2_7$	

Repeat Card 32 as needed.

Card 33 (Radiation Data, required for all lumps radiated to by structure lumps of this type)

1-5	F5.0	FA1	Gray-body shape factor, FA (in^2), between structure lumps of this type and the first lump 'radiated to' listed in the connections on the structure lump cards
.	.	.	.
.	.	.	.
.	.	.	.
66-70	F5.0	FA14	

Repeat Card 33 as needed.

Repeat Card 31 (followed by Cards 32 and 33, if needed) for each structure type.

Card 34 (Structure Lump Cards)

1-5	I5	LN	Lump number
6-10	I5	NTYPES	Type number
11-20	F10.5	STI	Initial temperature, °F
21-25	I5	NQICS	Incident heat curve number
26-30	I5	NTL1	First lump to which this structure lump has a connection either by conduction or radiation
.	.	.	.
.	.	.	.
.	.	.	.
66-70	I5	NTL9	Ninth lump to which this structure lump has a connection

Columns	Format	Title	Description
Card 35	(Additional connections, if required)		
1-5	I5	NTL10	10th lump
.	.	.	.
.	.	.	.
.	.	.	.
66-70	I5	NTL23	23rd lump

The order of the connected lumps is the same as the other in which the conduction and radiation data were given on the corresponding type card.

Repeat Card 35 as needed to supply all lumps to which the structure lump has a connection.

Repeat Card 34 (followed by Card 35, if needed) for each structure lump.

5.7.5 LOCAL TEMPERATURE PERTURBATION DATA CARDS

Card 36

1-5	I5	NLØCPT	Number of local perturbations (Enter zero if none desired and omit Card 37)

Card 37

1-5	I5	NSKIN	Skin area number = 1, Trunk = 2, Right arm = 3, Left arm = 4, Right leg = 5, Left leg = 6, Head = 7, Right hand = 8, Left hand = 9, Right foot = 10, Left foot
6-10	I5	NNODE	Skin tube lump number (loc. pert. model)
11-15	I5	NUGNOD	Undergarment tube lump number (loc. pert. model) Zero if no undergarment over skin
16-20	I5	NFLUID	Fluid (gas) lump number (loc. pert. model) (Must be in tube 21)
21-30	I10		Blank
31-35	I5	NKRDIFF	Diffusion factor curve number (Type 29)

Columns	Format	Title	Description
Card 37 (Continued)			
36-40	I5	NKRSWT	Sweat factor curve number (Type 29)
41-45	I5	NKRHHH	Heat transfer factor curve number (Type 29)

5.7.6 HEAT LEAK DATA CARDS

Columns	Format	Title	Description
Card 38			
1-5	I5	NGRHL	Number of groups of heat leak calculations (Enter zero if none desired and omit Cards 39 and 40)
Card 39			
1-5	I5	NG1	Number of paths of heat leak in group 1
10-15	A6	ID1	Six character identification of group 1
Card 40			
1-4	I4	JNODE	J node number
5	A1	JTYPE	J node code T = tube node S = structure node
6-10	I5	NCOND	Connection number for conduction value - has values 1 to n where n is the number of connections input on Card 28 or Card 34
11-15	I5	NRAD	Connection number for radiation value - has values 1 to n where n is the number of connections input on Card 28 or Card 34
16-19	I4	JNODE	J node number
20	A1	JTYPE	J node code T = tube node S = structure node
21-25	I5	NCOND	Connection number for conduction value - has values 1 to n where n is the number of connections input on Card 28 or Card 34
26-30	I5	NRAD	Connection number for radiation value - has values 1 to n where n is the number of connections input on Card 28 or Card 34

Two heat leak paths are input per card and Card 40 is repeated as necessary to supply NG1 paths. Repeat Card 39 followed by Card 40 as needed for NGRHL groups.

5.7.7 HEAT STORAGE DATA CARDS

Columns	Format	Title	Description
Card 41			
1-5	I5	NGRSH	Number of group of nodes for heat storage calculations (Enter zero if none desired and omit Cards 42 and 43)
Card 42			
1-5	I5	NGS1	Number of nodes in group 1
10-15	A6	IDS1	Six character identification of group 1
Card 43			
1-4	I4	NØDE1	First node number
5	A1	TYPE1	First node code F = fluid T = tube node S = structure node
6-9	I4	NØDE2	Second node number
10	A1	TYPE2	Second node code F = fluid node T = tube node S = structure node

.
.
.
etc. through column 70

Repeat Card 43 as necessary until NGS1 nodes have been supplied. Repeat Card 42 followed by Card 43 for NGRSH groups.

5.7.8 HELMET AND VISOR DATA CARDS

Columns	Format	Title	Description
Card 44			
1-5	I5	NHVPOS	Number of positions on helmet and visor (Enter zero if none desired and omit Card 45)
Card 45			
1-5	I5	NPOS	Position number

Columns	Format	Title	Description
Card 45 (Continued)			
6-10	I5	NTYPE	Position type 1 - Sun visor 2 - Impact visor 3 - Top of helmet 4 - Pressure bubble 5 - Face
11-15	I5	NØDE1	Node number for Mode 1 (Both visors down)
16-20	I5	NR1	Incident IR flux curve number
21-25	I5	NS1	Incident solar flux curve number
26-30	I5	NØDE2	Node number for Mode 2 (Sun visor up)
31-35	I5	NR2	Incident IR flux curve number
36-40	I5	NS2	Incident solar flux curve number
41-45	I5	NØDE3	Node number for Mode 3 (Both visors up)
46-50	I5	NR3	Incident IR flux curve number
51-55	I5	NS3	Incident solar flux curve number

Repeat Card 45 NHVPOS times

5.7.9 SUIT, GLOVES, AND EV BOOTS NODE IDENTIFICATION DATA CARDS

Card 46

1-5	I5	NLMPID	Total number of structure node comprising suit, gloves, & boots (Enter zero if none desired and omit Card 47)

Card 47

1-4	I4	LUMP	Node number
5	A1	IDEN	Identification code G = Glove node S = Suit node B = EV boot node

.
.
.
etc. through column 70

Repeat Card 47 as necessary to identify all suit, glove, and boot nodes.

5.7.10 Configuration/Associated Node Identification Data Cards

Columns	Format	Title	Description
Card 48			
1-5	I5	NLMPEN	Number of structure nodes to be identified with an environment mode (Enter zero if none desired and omit Card 49)
Card 49			
1-5	I5	LMP1	First structure node number
6-10	I5	NEN1	First environment mode identification code

.
.
.

etc. through column 70

Repeat Card 49 as necessary to supply NLMPEN sets of node number and code.

5.7.11 CURVE ASSIGNMENT DATA CARDS (USED FOR TYPES 19 AND 20 ONLY)

Columns	Format	Title	Description
Card 50			
1-5	I5	NNEVAH	Number of nodes with type 19 incident heat curves (Enter zero if none desired and omit Card 51)
Card 51			
1-4	I4	NØDE1	First node number
5	A1	TYPE1	First node code T = tube node S = structure node
6-10	I4	KURVE1	First type 19 incident heat curve number
11-14	I4	NØDE2	Second node number
15	A1	TYPE2	Second node code T = tube code S = structure node
16-20	I5	KURVE2	Second type 19 incident heat curve number

.
.
.

etc. through column 70

Repeat Card 51 as necessary to assign curve numbers to NNEVAH nodes.

Columns	Format	Title	Description
Card 52			
1-5	I5	NNEVAT	Number of nodes with type 20 prescribed temperature history curves (Enter zero if none desired and omit Card 53)
Card 53			
1-4	I4	NØDE1	First node number
5	A1	TYPE1	First node code T = tube node S = structure node
6-10	I5	KURVE1	First type 20 prescribed temperature curve number
11-14	I4	NØDE2	Second node number
15	A1	TYPE2	Second node code T = tube node S = structure node
16-20	I5	KURVE2	Second type 20 prescribed temperature curve number

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.
etc. through column 70

Repeat Card 53 as necessary to assign curve numbers to NNEVAT nodes.

5.7.12 PRESCRIBED WALL TEMPERATURE DATA CARDS (USED FOR TYPES 10 AND 11 ONLY)

Columns	Format	Title	Description
Card 54			
1-5	I5	NPRTEM	Number of lumps which have type 10 prescribed wall temperature curves (Enter zero if none desired and omit Card 55)
Card 55			
1-4	I4	NØDE1	First node number
5	A1	TYPE1	First node code T = tube node S = structure node
6-10	I5	KURVE1	First type 10 prescribed temperature curve number

Columns	Format	Title	Description
Card 55 (Continued)			
11-14	I4	NØDE2	Second node number
15	A1	TYPE2	Second node code
16-20	I5	KURVE2	Second type 10 prescribed temperature curve number

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.
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etc. through column 70

Repeat Card 55 as necessary to assign curve numbers to NTVARL nodes.

Card 56 (SIM Bay Prescribed Temperature Data Cards)

1-5	I5	NPTSIM	Number of SIMBAY structure lumps which have type 11 prescribed wall temperature curves (Enter zero if none desired and omit Card 57)

Card 57

1-5	I5	NØDE1	First node number
6-10	I5	KURVE1	First type 11 prescribed temperature curve number
11-15	I5	NØDE2	Second node number
16-20	I5	KURVE2	Second type 11 prescribed temperature curve number

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.
.

etc. through column 70

5.7.13 TIME VARIANT NODAL MASS DATA CARDS

Card 58

1-5	I5	NUMTVW	Number of nodes with type 30 time variant mass (Enter zero if none desired and omit Card 59)

Columns	Format	Title	Description
Card 59			
1-4	I4	NØDE1	First node number
5	A1	TYPE1	First node code T = tube node S = structure node
6-10	I5	KURVE1	First type 30 time variant mass factor curve number
11-14	I4	NØDE2	Second node number
15	A1	TYPE2	Second node code
16-20	I5	KURVE2	Second type 30 time variant mass factor curve number

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.
.
etc. through column 70

Repeat Card 59 as necessary to assign curve numbers to NUMTVW nodes.

5.7.14 TIME VARIANT NODAL CONNECTION DATA CARDS

Columns	Format	Title	Description
Card 60			
1-5	I5	NUMTVC	Number of type 30 time variant connections (Enter zero if none desired and omit Card 61)
Card 61			
1-4	I4	NØDE1	First node number
5	A1	TYPE1	First node code T = tube node S = structure node
6-10	I5	NLØC1	Connection number - has values 1 to n where n is the number of connections input on Card 28 or Card 34
11-15	I5	KURVE1	Type 30 time variant multiplying factor curve number
16-19	I4	NØDE2	Second node number
20		TYPE2	Second node code T = tube node S = structure node

Columns	Format	Title	Description
Card 61 (Continued)			
21-25	I5	NLØC2	Connection number
26-30	I5	KURVE2	Type 30 time variant multiplying factor curve number

.
.
.
etc. through column 60

Repeat Card 61 as necessary to supply NUMTVC time variant connections.

5.7.15 CURVE DATA CARDS

Card 62 (Curve Header Card)

1-5	I5	KCRV	Curve type
		0	Head loss coefficient = f (R_e)
		1	Fluid density, (lb_m/ft^3) = f (°F)
		2	Fluid viscosity, $\left(\frac{lbm}{ft^2 sec}\right)$ = f (°F)
		3	Friction factor for fluid (used when Re > 2000) F = f (R_e)
		4	Conductivity, (K/K_i) = f (°F)
		5	Specific heat, (Btu/lb_m °F) = f (°F)
		9	Incident heat, $\left(\frac{Btu}{hr\ ft^2}\right)$ = f (hrs)
		10	Wall temp, °F = f (hrs)
		11	SIMBAY wall temp, °F = f (hrs)
		12	Fluid temperature, °F = f (τ)
		19	Combined heat fluxes, (Btu/hr) = f (τ)
		20	Prescribed temperature histories, (°F) = f (τ)
		21	Radiant Interchange Mode 1. = Mode 1 2. = Mode 2 3. = Mode 3
		24	HHH Curve, $\left(\frac{Btu}{hr\text{-}ft^2 °F}\right)$ = f (lb/hr)
		29	Local perturbation multiplying factor
		30	Time variant factors: Mass factor = f (τ) Connection factor = f (τ)
		33	Bivariant curves: Compressibility factor, Z = f(PR,TR) Oxygen enthalpy, h = f(P,T)
		34	Time variant curves: Suit leak rate, lb/hr = f (τ) Metabolic load, Btu/hr = f (τ) Man efficiency, Percent/100 = f (τ)

Columns	Format	Title	Description
Card 62 (Continued)			
			Suit gas pressure, psia = f (τ)
			Gravity factor, fraction = f (τ)
			Cabin freestream velocity, ft/min = f (τ)
			Cabin ventilation efficiency, percent/ 100 = f (τ)
			Cabin gas pressure, psia = f (τ)
			ARS suit flowrate, lb/hr = f (τ)
			Oxygen pressure, psia = f (τ)
			Glycol water flowrate, lb/hr = f (τ)
			Regulator outlet pressure, psia = f (τ)
		35	System control curves
			OPS flowrate, lb/hr = f (τ) zero indicates OPS off
			Helmet mode = f (τ)
			0. = LEVA off
			1. = Both visors down
			2. = Sun visor up
			3. = Both visors up
			EMU configuration mode = f (τ)
6-10	I5	NC	Curve number
11-15	I5	NP	Number of points on curve, if KCRV = 33 NP equal the number of independent variable input first
16-20	Blank except for KCRV = 33		
	I5	NTU	Number of independent variables input second
21-25	Blank		
26-72	7A6	CTITLE	May be used for curve title
Card 63	(If KCRV ≠ 33)		
1-10	F10.5	X_1	Independent variable
11-20	F10.5	X_2	
21-30	F10.5	X_3	
etc.			
	F10.5	Y_1	Dependent variable
	F10.5	Y_2	
	F10.5	Y_3	
etc.			

Columns	Format	Title	Description

Card 63 (Continued)

Start Y_1 in the first field after X_{NP}. Do not write beyond column 70. If the number of points is 1, the value in columns 11-20 will be used for the dependent variable.

Card 63 (If KCRV = 33)

Columns	Format	Title	Description
1-5	F5.4	FR_1	Values of the first independent variable
6-10	F5.4	FR_2	
11-15	F5.4	FR_3	
etc.			
	F5.4	TU_1	Values of the second independent variable
	F5.4	TU_2	
	F5.4	TU_3	
etc.			
	F5.4	$P(FR_1,TU_1)$	Values of dependent variable
	F5.4	$P(FR_1,TU_2)$	
	F5.4	$P(FR_1,TU_3)$	
etc.			
	F5.4	$P(FR_2,TU_1)$	
	F5.4	$P(FR_2,TU_2$	
	F5.4	$P(FR_2,TU_3)$	
etc.			

End of Data

Columns	Format	Title	Description
1-5	I5	LCD	Input the number 13

6.0 LIST OF SYMBOLS

Alphabetic

A_f	Area for convective heat transfer, square inches
A_{ij}	Effective conduction or radiation area between lumps, square inches
c, c_p	Specific heat, BTU/lb-°F
CSA	Cross sectional area, square inches
D_h	Hydraulic diameter, inches
f	Friction factor used for turbulent or laminar flow pressure drop computations
(αA)	Gray-body configuration factor between lumps, square inches
FLL	Fluid lump length, inches
FRE	Factor applied to laminar flow friction factor to account for non-circular pipe flow
h_f, HHH	Heat transfer coefficient, BTU/hr-ft^2-°F
i	Lump number
j	Adjacent lump number
K	Fluid dynamic head losses
K	Thermal conductivity, BTU/hr-ft-°F
k_i	Thermal conductivity of a lump at the present temperature normalized by the thermal conductivity at which R_i was evaluated, e.g., K_i/K_{Ri} or K_j/K_{RJ}
L	Length from tube entrance, inches
Nu	Nusselt number
P	Pressure, psia
P_{SYS}	System pressure, psia
Pr	Prandtl number
$\dot{Q}$	Energy flux relative to a control volume

Re	Reynolds number
R_i, R_1	That portion of the conduction resistance from lump i to j which is attributed to i = $Y_j/K_j\ A_{ij}$, hr-°F/BTU
R_j, R_2	That portion of the conduction resistance from lump i to j which is attributed to j = $Y_j/K_j\ A_{ij}$, hr-°F/BTU
T	Temperature of a lump at time τ
T'	Temperature of a lump at time $\tau + \Delta\tau$
T'_{fu}	Upstream fluid lump temperature, °R
U_{ij}	Conductance between adjacent structure lumps, BTU/hr-°F
V	Fluid velocity, ft/sec
$\dot{w}$	Fluid flow rate, lb/hr
w	Weight of lump, lbs
WP	Wetted perimeter, inches
Y	A portion of the conduction path length between nodes, e.g., Y_i is that portion of the conduction path length between nodes i and j which lies in lump i

Greek Symbols

(αA)	Surface absorptance times incident heat application area, square inches
ΔP	Pressure drop, psi
$\Delta\tau$	Calculation time increment, hrs
σ	Stefan-Boltzmann constant $.173 \times 10^{-8}\ \frac{\text{BTU}}{\text{hr ft}^2(°\text{R})^4}$
τ	Time, hours
μ	Fluid viscosity, lbs/ft-sec

Subscripts

f	Fluid lump
fu	Upstream fluid lump
i	Lump under consideration
j	Lump adjacent to lump i
t	Tube

7.0 REFERENCES

1. Hixon, C. W., Phillips, M. A., "Extravehicular Mobility Unit Thermal Simulator", LTV Aerospace Corporation Report No. T155-03, 31 March 1973.

2. Dusinberre, G. M. "Heat Transfer Calculations by Finite Differences", International Textbook Company, Scranton, Penn., 1961

3. Leach, J. W., "Hybrid Implicit-Explicit Numerical Technique", LTV-MSC 350-DIR-13, February 1968.

4. Clark, T. B., "Finite Difference Methods of Heat Conduction Problems", M.S. Thesis, Southern Methodist University, 23 March 1961.

5. Leach, J. W., "Thermal Equilibrium Extrapolation Technique", LTV-MSC Report No. 00.1083, July 1968, page 22.

6. Chu, W. H., "Transient Heat Transfer with Radiation and Convection", Memorandum Enclosure to "Development of Generalized Computer Program and Radiant Heat Transfer", by D. R. Falconer and G. E. Nevill, Jr., Southwest Research Institute, San Antonio, Texas, December 1962.

7. Sellers, J. R., Tribus, Myron, Klein, S. J., "Heat Transfer to Laminar Flow in a Round Tube or Flat Conduit - The Graetz Problem Extended", Trans. ASME, Vol. 78, 1956, pp. 441-448.

8. Sieder, E. N., and Tate, G. E., "Industrial Engineering Chemistry", <u>28</u>, 1429-1436 (1936).

9. McAdams, W. H., "Heat Transmission", Third Edition, McGraw-Hill Book Company, Inc., New York, 1954, pp. 237.

10. Lundgren, T. S., Sparrow, E. M., Stan, J. B., "Pressure Drop Due to the Entrance Region in Ducts of Arbitrary Cross Section", Journal of Basic Engineering, Vol. 86, pp 620-626, 1964.

11. Morgan, L. W., Collett, G., and Cook, D. W., Jr., "Transient Metabolic Simulation Program", Program J 116, May 1969.

12. Environmental Heat Flux Routine, Version 4, Final Report, LTV Aerospace Report No. T155-01, March 1973.

13. Webb, C. M., "Geometrical Models of EVVA, EV Boots, EV Gloves, PLSS and OPS for Thermal Analysis Program", General Electric, Apollo Support Division, TIR-580-S-8140, May 1968.

14. Sarbeck, T. L., "Edit", Unpublished, dated 6 October 1966.

APPENDIX A

TABLE A-1
EMU/SIM BAY THERMAL MODEL NODE DESCRIPTION

TUBE NODE NO.	FLUID NODE NO.	DESCRIPTION
1	1	1ST LUMP IN TUBE NO. 1
2	2	2ND LUMP IN TUBE NO. 1
3	3	1ST RESTRICTOR LUMP IN TUBE NO. 1
4	4	2ND RESTRICTOR LUMP IN TUBE NO. 1
5	5	3RD RESTRICTOR LUMP IN TUBE NO. 1
6	6	4TH RESTRICTOR LUMP IN TUBE NO. 1
7	7	5TH RESTRICTOR LUMP IN TUBE NO. 1
8	8	6TH RESTRICTOR LUMP IN TUBE NO. 1
9	9	7TH RESTRICTOR LUMP IN TUBE NO. 1
10	10	8TH RESTRICTOR LUMP IN TUBE NO. 1
11	11	9TH RESTRICTOR LUMP IN TUBE NO. 1
12	12	10TH RESTRICTOR LUMP IN TUBE NO. 1
13	13	11TH RESTRICTOR LUMP IN TUBE NO. 1
14	14	12TH RESTRICTOR LUMP IN TUBE NO. 1
15	15	13TH RESTRICTOR LUMP IN TUBE NO. 1
16	16	14TH RESTRICTOR LUMP IN TUBE NO. 1
17	17	LUMP BET. RESTRICTOR AND CK VLV (TUBE 1)
18	18	CHECK VALVE IN TUBE NO. 1
19	19	LUMP DWNSTR OF CHECK VALVE (TUBE 1)
20	20	LUMP UPSTR OF JUNCTION (TUBE 1)
21	21	1ST LUMP IN TUBE NO. 2
22	22	2ND LUMP IN TUBE NO. 2
23	23	1ST RESTRICTOR LUMP IN TUBE NO. 2
24	24	2ND RESTRICTOR LUMP IN TUBE NO. 2
25	25	3RD RESTRICTOR LUMP IN TUBE NO. 2
26	26	4TH RESTRICTOR LUMP IN TUBE NO. 2
27	27	5TH RESTRICTOR LUMP IN TUBE NO. 2
28	28	6TH RESTRICTOR LUMP IN TUBE NO. 2
29	29	7TH RESTRICTOR LUMP IN TUBE NO. 2
30	30	8TH RESTRICTOR LUMP IN TUBE NO. 2
31	31	9TH RESTRICTOR LUMP IN TUBE NO. 2
32	32	10TH RESTRICTOR LUMP IN TUBE NO. 2
33	33	11TH RESTRICTOR LUMP IN TUBE NO. 2
34	34	12TH RESTRICTOR LUMP IN TUBE NO. 2
35	35	13TH RESTRICTOR LUMP IN TUBE NO. 2
36	36	14TH RESTRICTOR LUMP IN TUBE NO. 2
37	37	LUMP BET. RESTRICTOR AND CK VLV (TUBE 2)
38	38	CHECK VALVE IN TUBE NO. 2
39	39	LUMP DWNSTR OF CHECK VALVE IN TUBE NO. 2
40	40	LUMP UPSTR OF JUNCTION (TUBE 2)
41	41	1ST LUMP IN TUBE NO. 3
42	42	2ND LUMP IN TUBE NO. 3
43	43	1ST RESTRICTOR LUMP IN TUBE NO. 3
44	44	2ND RESTRICTOR LUMP IN TUBE NO. 3
45	45	3RD RESTRICTOR LUMP IN TUBE NO. 3
46	46	4TH RESTRICTOR LUMP IN TUBE NO. 3
47	47	5TH RESTRICTOR LUMP IN TUBE NO. 3
48	48	6TH RESTRICTOR LUMP IN TUBE NO. 3
49	49	7TH RESTRICTOR LUMP IN TUBE NO. 3
50	50	8TH RESTRICTOR LUMP IN TUBE NO. 3

51	51	9TH RESTRICTOR LUMP IN TUBE NO. 3
52	52	10TH RESTRICTOR LUMP IN TUBE NO. 3
53	53	11TH RESTRICTOR LUMP IN TUBE NO. 3
54	54	12TH RESTRICTOR LUMP IN TUBE NO. 3
55	55	13TH RESTRICTOR LUMP IN TUBE NO. 3
56	56	14TH RESTRICTOR LUMP IN TUBE NO. 3
57	57	LUMP BET. RESTRICTOR AND CK VLV (TUBE 3)
58	58	CHECK VALVE IN TUBE NO. 3
59	59	LUMP DWNSTR OF CHECK VALVE TUBE 3
60	60	LUMP UPSTR OF JUNCTION (TUBE 3)
61	61	1ST LUMP IN COOLANT LINE TUBE 4
62	62	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 3
63	63	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 4
64	64	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 5
65	65	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 6
66	66	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 7
67	67	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 8
68	68	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 9
69	69	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 10
70	70	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 11
71	71	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 12
72	72	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 13
74	74	COOLANT LINE CONNECTING NODE
73	73	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 14
75	75	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 23
76	76	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 24
77	77	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 25
78	78	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 26
79	79	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 27
80	80	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 28
81	81	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 29
82	82	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 30
83	83	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 31
84	84	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 32
85	85	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 33
86	86	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 34
87	87	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 35
89	89	COOLANT LIN CONNECTING NODE
88	88	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 36
90	90	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 43
91	91	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 44
92	92	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 45
93	93	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 46
94	94	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 47
95	95	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 48
96	96	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 49
97	97	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 50
98	98	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 51
99	99	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 52
100	100	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 53
101	101	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 54
102	102	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 55
103	103	GLY LINE TUBE LMP CORRES TO RESTRICTOR LMP 56
104	104	COOLANT OUTLET NODE
105	105	1ST LUMP BET. JUNCTION AND REGULATOR

106	106	2ND LUMP BET. JUNCTION AND REGULATOR
107	107	EVA PANEL SHUT OFF VALVE
109	109	REGULATOR
108	108	LUMP BET. S/O VALVE AND REGULATOR
110	110	LUMP BET. REG. AND QUICK DISCONN.
111	111	UMBILICAL LUMP NO. 1
112	112	UMBILICAL LUMP NO. 2
113	113	UMBILICAL LUMP NO. 3
114	114	UMBILICAL LUMP NO. 4
115	115	UMBILICAL LUMP NO. 5
116	116	UMBILICAL LUMP NO. 6
117	117	UMBILICAL LUMP NO. 7
118	118	UMBILICAL LUMP NO. 8
119	119	UMBILICAL LUMP NO. 9
120	120	UMBILICAL LUMP NO. 10
121	121	UMBILICAL LUMP NO. 11
122	122	UMBILICAL LUMP NO. 12
123	123	UMBILICAL LUMP NO. 13
124	124	UMBILICAL LUMP NO. 14
125	125	UMBILICAL LUMP NO. 15
126	126	SUIT CONTROL UNIT
127	127	OPS HEATER (NON-OPERATIVE)
128	128	DUMMY NODE NECESSARY
129	129	OPS REGULATOR
130	130	TUBE LMP BET. OPS REG. AND OPS UMBIL.
131	131	OPS UMBILICAL
132	132	DUMMY 1ST LUMP OF TUBE 9
133	133	DUMMY NODE NECESSARY
134	134	DUMMY NODE SUIT OUTLET
135	135	CREWMAN HEAD SKIN
136	136	CREWMAN TRUNK SKIN
137	137	CREWMAN RT ARM SKIN
138	138	CREWMAN RT. HAND SKIN
139	139	CREWMAN LT ARM SKIN
140	140	CREWMAN LT HAND SKIN
141	141	CREWMAN RT. LEG SKIN
142	142	CREWMAN RT. FOOT SKIN
143	143	CREWMAN LT. LEG SKIN
144	144	CREWMAN LT FOOT SKIN
145	135	PGA- INTERIOR - NECK
146	135	PGA- INTERIOR - NECK
147	136	PGA- INTERIOR - TRUNK
148	136	PGA- INTERIOR - TRUNK
149	136	PGA- INTERIOR - TRUNK
150	136	PGA- INTERIOR - TRUNK
151	136	PGA- INTERIOR - TRUNK
152	136	PGA- INTERIOR - TRUNK
153	139	PGA- INTERIOR - LT ARM
154	137	PGA- INTERIOR - RT ARM
155	139	PGA- INTERIOR - LT ARM
156	137	PGA- INTERIOR - RT ARM
157	137	PGA- INTERIOR - RT ARM
158	139	PGA- INTERIOR - LT ARM
159	137	PGA- INTERIOR - RT ARM
160	139	PGA- INTERIOR - LT ARM

161	138	PGA- INTERIOR - RT HAND
162	138	PGA- INTERIOR - RT HAND
163	140	PGA- INTERIOR - LT HAND
164	140	PGA- INTERIOR - LT HAND
165	135	PRESSURE HELMET BUBBLE
166	135	PRESSURE HELMET BUBBLE
167	135	PRESSURE HELMET BUBBLE
168	135	PRESSURE HELMET BUBBLE
169	135	PRESSURE HELMET BUBBLE
170	135	PRESSURE HELMET BUBBLE
171	135	PRESSURE HELMET BUBBLE
172	135	PRESSURE HELMET BUBBLE
173	135	PRESSURE HELMET BUBBLE
174	135	PRESSURE HELMET BUBBLE
175	135	PRESSURE HELMET BUBBLE
176	135	PRESSURE HELMET BUBBLE
177	135	PRESSURE HELMET BUBBLE
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179	135	PRESSURE HELMET BUBBLE
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184	135	PRESSURE HELMET BUBBLE
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201	135	PRESSURE HELMET BUBBLE
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216	135	PRESSURE HELMET BUBBLE
217	135	PRESSURE HELMET BUBBLE
218	135	PRESSURE HELMET BUBBLE
219	135	PRESSURE HELMET BUBBLE
220	135	PRESSURE HELMET BUBBLE
221	135	PRESSURE HELMET BUBBLE
222	135	PRESSURE HELMET BUBBLE
223	135	PRESSURE HELMET BUBBLE
224	135	PRESSURE HELMET BUBBLE
225	135	PRESSURE HELMET BUBBLE
226	135	PRESSURE HELMET BUBBLE
227	141	PGA - INTERIOR - RT. LEG
228	143	PGA - INTERIOR - LT. LEG
229	141	PGA - INTERIOR - RT. LEG
230	143	PGA - INTERIOR - LT. LEG
231	141	PGA - INTERIOR - RT. LEG
232	143	PGA - INTERIOR - LT. LEG
233	141	PGA - INTERIOR - RT. LEG
234	143	PGA - INTERIOR - LT. LEG
235	142	PGA - INTERIOR - RT. FOOT
236	144	PGA - INTERIOR - LT. FOOT
237	142	PGA - INTERIOR - RT. FOOT
238	144	PGA - INTERIOR - LT. FOOT
239	142	PGA - INTERIOR - RT. FOOT
240	144	PGA - INTERIOR - LT. FOOT
241	136	PGA - ELECT. CONN.
242	136	OPS - O2 CONN.
243	136	O2 INLET CONN. (UMBILICAL)
244	136	O2 PURGE VALVE
245	137	SUIT PRESSURE GAGE
246	139	SUIT RELIEF VALVE
247	135	NECKRING
248	135	NECKRING
249	135	NECKRING
250	135	NECKRING
251	136	UNDERGARMENT TRUNK
252	137	UNDERGARMENT RT. ARM
253	139	UNDERGARMENT LT. ARM
254	141	UNDERGARMENT RT. LEG
255	143	UNDERGARMENT LT. LEG
256	142	UNDERGARMENT RT. FOOT
257	144	UNDERGARMENT LT. FOOT
258	145	GLY LUMP CORRES TO RESTRICTOR LUMP 15
258	145	GLY TUBE LMP CORRES TO RESTICTOR LMP 15
259	146	GLY TUBE LMP CORRES TO RESTICTOR LMP 16

TABLE A-2
EMU BASELINE MODEL NODAL BREAKDOWN DATA

STRUCTURE NODE	LOCATION/DESCRIPTION
1	LEVA THERMAL COVER
2	LEVA THERMAL COVER
3	LEVA THERMAL COVER
4	LEVA THERMAL COVER
5	LEVA THERMAL COVER
6	LEVA THERMAL COVER
7	LEVA THERMAL COVER
8	LEVA THERMAL COVER
9	LEVA THERMAL COVER
10	LEVA THERMAL COVER
11	SUN VISOR (HELMET MODE 1)
12	SUN VISOR (HELMET MODE 1)
13	SUN VISOR (HELMET MODE 1)
14	SUN VISOR (HELMET MODE 1)
15	SUN VISOR (HELMET MODE 1)
16	SUN VISOR (HELMET MODE 1)
17	PROTECTIVE VISOR (HELMET MODE 1)
18	PROTECTIVE VISOR (HELMET MODE 1)
19	PROTECTIVE VISOR (HELMET MODE 1)
20	PROTECTIVE VISOR (HELMET MODE 1)
21	PROTECTIVE VISOR (HELMET MODE 1)
22	PROTECTIVE VISOR (HELMET MODE 1)
23	DUMMY
24	DUMMY
25	DUMMY
26	DUMMY
27	DUMMY
28	DUMMY
29	DUMMY
30	DUMMY
31	DUMMY
32	RCU HARDSHELL
33	DUMMY
34	DUMMY
35	DUMMY
36	DUMMY
37	DUMMY
38	DUMMY
39	ITMG EXTERIOR
40	ITMG EXTERIOR
41	ITMG EXTERIOR
42	ITMG EXTERIOR
43	ITMG EXTERIOR
44	ITMG EXTERIOR
45	ITMG EXTERIOR
46	ITMG EXTERIOR
47	ITMG EXTERIOR
48	ITMG EXTFRIOR
49	ITMG EXTERIOR
50	ITMG EXTERIOR

51	ITMG EXTERIOR
52	ITMG EXTERIOR
53	ITMG EXTERIOR
54	ITMG EXTERIOR
55	ITMG EXTERIOR
56	ITMG EXTERIOR
57	ITMG EXTERIOR
58	ITMG EXTERIOR
59	ITMG EXTERIOR
60	ITMG INSULATION
61	ITMG INSULATION
62	ITMG INSULATION
63	ITMG INSULATION
64	ITMG INSULATION
65	ITMG INSULATION
66	ITMG INSULATION
67	ITMG INSULATION
68	ITMG INSULATION
69	ITMG INSULATION
70	ITMG INSULATION
71	ITMG INSULATION
72	ITMG INSULATION
73	ITMG INSULATION
74	ITMG INSULATION
75	ITMG INSULATION
76	ITMG INSULATION
77	ITMG INSULATION
78	ITMG INSULATION
79	ITMG INSULATION
80	ITMG INSULATION
81	ITMG INTERIOR
82	ITMG INTERIOR
83	ITMG INTERIOR
84	ITMG INTERIOR
85	ITMG INTERIOR
86	ITMG INTERIOR
87	ITMG INTERIOR
88	ITMG INTERIOR
89	ITMG INTERIOR
90	ITMG INTERIOR
91	ITMG INTERIOR
92	ITMG INTERIOR
93	ITMG INTERIOR
94	ITMG INTERIOR
95	ITMG INTERIOR
96	ITMG INTERIOR
97	ITMG INTERIOR
98	ITMG INTERIOR
99	ITMG INTERIOR
100	ITMG INTERIOR
101	ITMG INTERIOR
102	DUMMY
103	DUMMY
104	OPS OXYGEN TANK, LEFT
105	OPS OXYGEN TANK, RIGHT

106	OPS FRAME
107	OPS PLATE
108	DUMMY
109	DUMMY
110	OPS OXYGEN TANK SUPPORT
111	OPS OXYGEN TANK SUPPORT
112	OPS FRAME
113	OPS FRAME
114	OPS FRAME
115	OPS FRAME
116	OPS FRAME
117	OPS FRAME
118	OPS FRAME
119	OPS FRAME
120	OPS FRAME
121	OPS HARDSHELL (BACK)
122	OPS HARDSHELL (L.S.)
123	OPS HARDSHELL (R.S.)
124	OPS HARDSHELL (TOP)
125	OPS THERMAL COVER (BACK INTERIOR)
126	OPS THERMAL COVER (L.S. INTERIOR)
127	OPS THERMAL COVER (R.S. INTERIOR)
128	OPS THERMAL COVER (TOP INTERIOR)
129	OPS THERMAL COVER (FRONT INTERIOR)
130	OPS THERMAL COVER (BACK EXTERIOR)
131	OPS THERMAL COVER (L.S. EXTERIOR)
132	OPS THERMAL COVER (R.S. EXTERIOR)
133	OPS THERMAL COVER (TOP EXTERIOR)
134	OPS THERMAL COVER (FRONT EXTERIOR)
135	OPS HARDSHELL (FRONT)
136	DUMMY
137	DUMMY
138	DUMMY
139	DUMMY
140	DUMMY
141	DUMMY
142	DUMMY
143	DUMMY
144	DUMMY
145	DUMMY
146	DUMMY
147	DUMMY
148	DUMMY
149	DUMMY
150	SPACE NODE
151	DUMMY
152	DUMMY
153	DUMMY
154	DUMMY
155	DUMMY
156	DUMMY
157	DUMMY
158	DUMMY
159	DUMMY
160	DUMMY

161	DUMMY
162	DUMMY
163	DUMMY
164	DUMMY
165	DUMMY
166	DUMMY
167	DUMMY
168	DUMMY
169	DUMMY
170	DUMMY
171	DUMMY
172	DUMMY
173	OXYGEN IN LEFT HAND OPS BOTTLE
174	OXYGEN IN RIGHT HAND OPS BOTTLE
175	DUMMY
176	OPS THERMAL COVER (BOTTOM INTERIOR)
177	OPS THERMAL COVER (BOTTOM EXTERIOR)
178	DUMMY
179	DUMMY
180	DUMMY
181	SUN VISOR (HELMET MODE 2)
182	SUN VISOR (HELMET MODE 2)
183	SUN VISOR (HELMET MODE 2)
184	SUN VISOR (HELMET MODE 2)
185	SUN VISOR (HELMET MODE 2)
186	SUN VISOR (HELMET MODE 2)
187	PROTECTIVE VISOR (HELMET MODE 2)
188	PROTECTIVE VISOR (HELMET MODE 2)
189	PROTECTIVE VISOR (HELMET MODE 2)
190	PROTECTIVE VISOR (HELMET MODE 2)
191	PROTECTIVE VISOR (HELMET MODE 2)
192	PROTECTIVE VISOR (HELMET MODE 2)
193	SUN VISOR (HELMET MODE 3)
194	SUN VISOR (HELMET MODE 3)
195	SUN VISOR (HELMET MODE 3)
196	SUN VISOR (HELMET MODE 3)
197	SUN VISOR (HELMET MODE 3)
198	SUN VISOR (HELMET MODE 3)
199	PROTECTIVE VISOR (HELMET MODE 3)
200	PROTECTIVE VISOR (HELMET MODE 3)
201	PROTECTIVE VISOR (HELMET MODE 3)
202	PROTECTIVE VISOR (HELMET MODE 3)
203	PROTECTIVE VISOR (HELMET MODE 3)
203	PROTECTIVE VISOR (HELMET MODE 3)
204	PROTECTIVE VISOR (HELMET MODE 3)
205	LEVA THERMAL COVER (HELMET MODE 2)
206	LEVA THERMAL COVER (HELMET MODE 2)
207	LEVA THERMAL COVER (HELMET MODE 2)
208	LEVA THERMAL COVER (HELMET MODE 2)
209	LEVA THERMAL COVER (HELMET MODE 2)
210	LEVA THERMAL COVER (HELMET MODE 2)
211	DEEP SPACE(HELMENT MODE 2)
212	DEEP SPACE(HELMENT MODE 1)
213	DUMMY
214	DUMMY

215	DUMMY
216	DUMMY
217	PGA EXTERIOR
218	PGA EXTERIOR
219	PGA EXTERIOR
220	PGA EXTERIOR
221	PGA EXTERIOR
222	PGA EXTERIOR
223	PGA EXTERIOR
224	PGA EXTERIOR
225	PGA EXTERIOR
226	PGA EXTERIOR
227	PGA EXTERIOR
228	PGA EXTERIOR
229	PGA EXTERIOR
230	PGA EXTERIOR
231	PGA EXTERIOR
232	PGA EXTERIOR
233	PGA EXTERIOR
234	PGA EXTERIOR
235	PGA EXTERIOR
236	PGA EXTERIOR
237	PGA EXTERIOR
238	SUN VISOR (HELMET MODE 1)
239	SUN VISOR (HELMET MODE 1)
240	SUN VISOR (HELMET MODE 1)
241	SUN VISOR (HELMET MODE 1)
242	SUN VISOR (HELMET MODE 1)
243	SUN VISOR (HELMET MODE 1)
244	SUN VISOR (HELMET MODE 1)
245	SUN VISOR (HELMET MODE 1)
246	SUN VISOR (HELMET MODE 1)
247	SUN VISOR (HELMET MODE 1)
248	SUN VISOR (HELMET MODE 1)
249	SUN VISOR (HELMET MODE 1)
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251	SUN VISOR (HELMET MODE 1)
252	SUN VISOR (HELMET MODE 1)
253	SUN VISOR (HELMET MODE 1)
254	SUN VISOR (HELMET MODE 1)
255	SUN VISOR (HELMET MODE 1)
256	SUN VISOR (HELMET MODE 2)
257	SUN VISOR (HELMET MODE 2)
258	SUN VISOR (HELMET MODE 2)
259	SUN VISOR (HELMET MODE 2)
260	SUN VISOR (HELMET MODE 2)
261	SUN VISOR (HELMET MODE 2)
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263	SUN VISOR (HELMET MODE 2)
264	SUN VISOR (HELMET MODE 2)
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270	SUN VISOR (HELMET MODE 2)
271	SUN VISOR (HELMET MODE 2)
272	SUN VISOR (HELMET MODE 2)
273	SUN VISOR (HELMET MODE 2)
274	SUN VISOR (HELMET MODE 3)
275	SUN VISOR (HELMET MODE 3)
276	SUN VISOR (HELMET MODE 3)
277	SUN VISOR (HELMET MODE 3)
278	SUN VISOR (HELMET MODE 3)
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281	SUN VISOR (HELMET MODE 3)
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286	SUN VISOR (HELMET MODE 3)
287	SUN VISOR (HELMET MODE 3)
288	SUN VISOR (HELMET MODE 3)
289	SUN VISOR (HELMET MODE 3)
290	SUN VISOR (HELMET MODE 3)
291	SUN VISOR (HELMET MODE 3)
292	DUMMY
293	PROTECTIVE VISOR (HELMET MODE 1)
294	PROTECTIVE VISOR (HELMET MODE 1)
295	PROTECTIVE VISOR (HELMET MODE 1)
296	PROTECTIVE VISOR (HELMET MODE 1)
297	PROTECTIVE VISOR (HELMET MODE 1)
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310	PROTECTIVE VISOR (HELMET MODE 1)
311	PROTECTIVE VISOR (HELMET MODE 2)
312	PROTECTIVE VISOR (HELMET MODE 2)
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329	PROTECTIVE VISOR (HELMET MODE 3)
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344	PROTECTIVE VISOR (HELMET MODE 3)
345	PROTECTIVE VISOR (HELMET MODE 3)
346	PROTECTIVE VISOR (HELMET MODE 3)
347	LEVA SHELL
348	LEVA SHELL
349	LEVA SHELL
350	LEVA SHELL
351	LEVA SHELL
352	LEVA SHELL
353	LEVA SHELL
354	LEVA SHELL
355	LEVA SHELL
356	LEVA SHELL
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378	LEVA SHELL
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380	LEVA SHELL
381	LEVA SHELL
382	LEVA SHELL
383	LEVA SHELL
384	LEVA SHELL
385	LEVA THERMAL COVER
386	LEVA THERMAL COVER
387	LEVA THERMAL COVER
388	LEVA THERMAL COVER
389	LEVA THERMAL COVER
390	LEVA THERMAL COVER
391	LEVA THERMAL COVER
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402	LEVA THERMAL COVER
403	LEVA THERMAL COVER
404	LEVA THERMAL COVER
405	LEVA THERMAL COVER
406	LEVA THERMAL COVER
407	ITMG EXTERIOR
408	ITMG EXTERIOR
409	ITMG EXTERIOR
410	ITMG EXTERIOR
411	ITMG EXTERIOR
412	ITMG EXTERIOR
413	ITMG EXTERIOR
414	ITMG EXTERIOR
415	ITMG EXTERIOR
416	ITMG EXTERIOR
417	ITMG EXTERIOR
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419	ITMG EXTERIOR
420	ITMG EXTERIOR
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455	ITMG EXTERIOR
456	ITMG EXTERIOR
457	ITMG EXTERIOR
458	ITMG EXTERIOR
459	ITMG EXTERIOR
460	ITMG EXTERIOR
461	ITMG EXTERIOR
462	ITMG EXTERIOR
463	ITMG EXTERIOR
464	ITMG EXTERIOR
465	ITMG EXTERIOR
466	BOOT SOLE
467	ITMG EXTERIOR
468	ITMG EXTERIOR
469	ITMG EXTERIOR
470	ITMG EXTERIOR
471	ITMG EXTERIOR
472	ITMG EXTERIOR
473	BOOT SOLE
474	SUIT ELECTRICAL CONNECTOR (EXTERIOR)
475	ITMG INTERIOR
476	RIGHT HAND INLET O2 CONNECTOR (EXTERIOR)
477	LEFT HAND INLET O2 CONNECTOR (EXTERIOR)
478	RIGHT HAND OUTLET O2 CONNECTOR (EXTERIOR)
479	PGA EXTERIOR
480	SUIT PRESSURE GAGE THERMAL COVER (EXTERIOR)
481	SUIT RELIEF VALVE THERMAL COVER (EXTERIOR)
482	ITMG INSULATION
483	ITMG INSULATION
484	ITMG INSULATION
485	ITMG INSULATION
486	ITMG INSULATION
487	ITMG INSULATION
488	ITMG INSULATION
489	ITMG INSULATION

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543	ITMG INSULATION
544	ITMG INSULATION

545	ITMG INSULATION
546	ITMG INSULATION
547	ITMG INSULATION
548	ITMG INSULATION
549	ITMG INTERIOR
550	ITMG INTERIOR
551	ITMG INTERIOR
552	ITMG INTERIOR
553	ITMG INTERIOR
554	ITMG INTERIOR
555	ITMG INTERIOR
556	ITMG INTERIOR
557	ITMG INTERIOR
558	ITMG INTERIOR
559	ITMG INTERIOR
560	ITMG INTERIOR
561	PGA EXTERIOR
562	PGA EXTERIOR
563	PGA EXTERIOR
564	PGA EXTERIOR
565	PGA EXTERIOR
566	PGA EXTERIOR
567	PGA EXTERIOR
568	PGA EXTERIOR
569	PGA EXTERIOR
570	PGA EXTERIOR
571	PGA EXTERIOR
572	PGA EXTERIOR
573	SUIT PRESSURE GAGE THERMAL COVER INSULATION
574	SUIT PRESSURE GAGE THERMAL COVER INTERIOR
575	SUIT PRESSURE GAGE
576	SUIT RELIEF VALVE THERMAL COVER INSULATION
577	SUIT RELIEF VALVE THERMAL COVER INTERIOR
578	SUIT RELIEF VALVE
579	OPS O2 UMBILICAL SHEATH EXTERIOR
580	OPS O2 UMBILICAL SHEATH INSULATION
581	OPS O2 UMBILICAL SHEATH INTERIOR
582	OPS O2 UMBILICAL SHEATH EXTERIOR
583	OPS O2 UMBILICAL SHEATH INSULATION
584	OPS O2 UMBILICAL SHEATH INTERIOR
585	OPS O2 UMBILICAL SHEATH EXTERIOR
586	OPS O2 UMBILICAL SHEATH INSULATION
587	OPS O2 UMBILICAL SHEATH INTERIOR
588	COMMAND MODULE SKIN
589	COMMAND MODULE SKIN
590	COMMAND MODULE SKIN
591	COMMAND MODULE SKIN
592	COMMAND MODULE SKIN
593	SM SKIN BETWEEN EPS RADIATORS
594	SM SKIN BETWEEN EPS RADIATORS
595	SM SKIN BETWEEN EPS RADIATORS
596	EPS RADIATOR PANEL
597	EPS RADIATOR PANEL
598	EPS RADIATOR PANEL
599	EPS RADIATOR PANEL

600	SM SKIN ABOVE ECS RADIATOR
601	SM SKIN ABOVE ECS RADIATOR
602	SM SKIN SIM BAY
603	SM SKIN ABOVE ECS RADIATOR
604	SM SKIN ABOVE ECS RADIATOR
605	ECS RADIATOR PANEL
606	ECS RADIATOR PANEL
607	ECS RADIATOR PANEL
608	ECS RADIATOR PANEL
609	SM SKIN BELOW ECS RADIATOR
610	SM SKIN BELOW ECS RADIATOR
611	SM SKIN BELOW SIM BAY
612	SM SKIN BELOW ECS RADIATOR
613	SM SKIN BELOW ECS RADIATOR
614	COMPARTMENT 1
615	COMPARTMENT 1
616	FLOOR OF COMPARTMENT 2
617	WALL OF COMPARTMENT 2
618	UPPER BULKHEAD - COMPARTMENT 2
619	SLANTED REAR BULKHEAD - COMPARTMENT 2
620	WALL OF COMPARTMENT 2
621	VERTICAL REAR BULKHEAD - COMPARTMENT
622	COMPARTMENT 3
623	OPEN HATCH DOOR
624	HATCH OPENING
625	LMP IN HATCH OPENING
626	QUAD A THRUSTER SURFACE
627	QUAD A THRUSTER SURFACE
628	QUAD A THRUSTER SURFACE
629	QUAD A THRUSTER SURFACE
630	QUAD B THRUSTER SURFACE
631	QUAD B THRUSTER SURFACE
632	QUAD B THRUSTER SURFACE
633	QUAD B THRUSTER SURFACE
634	SUBSATELLITE BOX
635	SUBSATELLITE BOX
636	SUBSATELLITE BOX
637	SUBSATELLITE BOX
638	FOOT RESTRAINT
639	PAN CAMERA
640	PAN CAMERA
641	PAN CAMERA
642	PAN CAMERA
643	PAN CAMERA
644	COMMAND MODULE SKIN
645	CASSETTE, PANORAMIC CAMERA
646	CASSETTE, MAPPING CAMERA
647	RAILING
648	LIFE SUPPORT UMBILICAL INTERIOR
649	LIFE SUPPORT UMBILICAL INTERIOR
650	LIFE SUPPORT UMBILICAL INTERIOR
651	LIFE SUPPORT UMBILICAL INTERIOR
652	LIFE SUPPORT UMBILICAL INTERIOR
653	LIFE SUPPORT UMBILICAL INTERIOR
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661	LIFE SUPPORT UMBILICAL INTERIOR
662	LIFE SUPPORT UMBILICAL INTERIOR
663	LIFE SUPPORT UMBILICAL INSULATION
664	LIFE SUPPORT UMBILICAL INSULATION
665	LIFE SUPPORT UMBILICAL INSULATION
666	LIFE SUPPORT UMBILICAL INSULATION
667	LIFE SUPPORT UMBILICAL INSULATION
668	LIFE SUPPORT UMBILICAL INSULATION
669	LIFE SUPPORT UMBILICAL INSULATION
670	LIFE SUPPORT UMBILICAL INSULATION
671	LIFE SUPPORT UMBILICAL INSULATION
672	LIFE SUPPORT UMBILICAL INSULATION
673	LIFE SUPPORT UMBILICAL INSULATION
674	LIFE SUPPORT UMBILICAL INSULATION
675	LIFE SUPPORT UMBILICAL INSULATION
676	LIFE SUPPORT UMBILICAL INSULATION
677	LIFE SUPPORT UMBILICAL INSULATION
678	LIFE SUPPORT UMBILICAL EXTERIOR
679	LIFE SUPPORT UMBILICAL EXTERIOR
680	LIFE SUPPORT UMBILICAL EXTERIOR
681	LIFE SUPPORT UMBILICAL EXTERIOR
682	LIFE SUPPORT UMBILICAL EXTERIOR
683	LIFE SUPPORT UMBILICAL EXTERIOR
684	LIFE SUPPORT UMBILICAL EXTERIOR
685	LIFE SUPPORT UMBILICAL EXTERIOR
686	LIFE SUPPORT UMBILICAL EXTERIOR
687	LIFE SUPPORT UMBILICAL EXTERIOR
688	LIFE SUPPORT UMBILICAL EXTERIOR
689	LIFE SUPPORT UMBILICAL EXTERIOR
690	LIFE SUPPORT UMBILICAL EXTERIOR
691	LIFE SUPPORT UMBILICAL EXTERIOR
692	LIFE SUPPORT UMBILICAL EXTERIOR